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HDL-TM-77-15

December 1977

A Proposed Army Structure for the Assessment of Smoke Effectiveness

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER HDL-TM-77-15	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 A Proposed Army Structure for the Assessment of Smoke Effectivness		5. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
		6. PERFORMING ORG. REPORT NUMBER 16
7. AUTHOR(s) 10 Dominick A. Giglio, Robert G. Humphrey		8. CONTRACT OR GRANT NUMBER(s) DA: 1L765702D671
9. PERFORMING ORGANIZATION NAME AND ADDRESS Harry Diamond Laboratories, 2800 Powder Mill Road, Adelphi, MD 20783		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Ele: 6.57.02.A
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Materiel Development and Readiness Command, Alexandria, VA 22333		12. REPORT DATE 11 December 1977
		13. NUMBER OF PAGES 81
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) 12 82p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

HDL Project: 1227V1

DRCMS Code: 6757026710012

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Smoke
Smoke testing
System performance in smoke

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of an investigation into the Army's testing capability with respect to smoke and electro-optical weapon systems in smoke. The approach advocated for such testing is a comprehensive one in which the operational and developmental aspects of systems are considered, producing an assessment of the system's (over)

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effectiveness in a battlefield environment. Also advocated in the report is the organization of existing Army resources into a formal test structure, under the joint leadership of the Project Manager for Smoke (representing the developmental, or technical, side of effectiveness assessment) and the Combined Arms Combat Developments Activity (representing the operational, or tactical, side). A brief survey of existing Army test resources is also presented, with some technical discussion on system performance and smoke testing technology and instrumentation.

This report was first published in December of 1976 in a preliminary form. Because of the emphasis within the Army to organize its resources, the document was given wide distribution at that time. Many of the report's recommendations and suggested policies have, in effect, been implemented since that period. The publication of this final version serves only to formally document the effort and distribution is therefore limited.

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No change per Ms. Neida McNeil, HDL

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1. INTRODUCTION

Soviet tactical doctrine includes heavy use of smoke, while U.S. doctrine heavily emphasizes the use of sensors and weapons which would be adversely affected by smoke. (For this discusssion, the term "smoke" implies any manmade aerosol employed for the screening or obscuration of military activities.) In addition, U.S. smoke inventory and tactics have fallen into a neglected state. The existence of such a situation is quite serious and requires a response of major proportions by the military. Recognition of these well-known facts has caused, in recent months, a great flurry of activity within the U.S. Army with respect to the development of smoke-generating systems and the testing of electro-optical (EO) weapon systems in smoke.

Until very recently, this activity consisted mainly of somewhat uncoordinated efforts by a variety of Army agencies to bring previously low-level or nonexistent programs to the point where new and important (but not always clearly defined) requirements concerning smoke could be addressed. One of the major problems faced by this smoke community was the development of an entire technology for conducting meaningful tests of smoke and of the effect of smoke on various systems. Not only were the technical problems associated with the testing of smoke to be contended with, but investigators were required to operate without any formal structure within the Army for planning, coordinating, and executing such tests. Each group was therefore left to its own resources for solving technical problems, establishing test methodology, acquiring smoke sources and test sites, executing the test, collecting the data, reducing the data, and disseminating the results. Of course, operation under such a system can lead to a great proliferation of tests, each executed with its own special point of view emphasized (be it the view of a smoke developer, a weapons system developer, a battle analyst, etc.), and each with its own set of ground rules, which may or may not be relevant. Such tests can produce results which may never reach interested workers in other groups or results which, because of the chosen methodology or instrumentation (or lack of instrumentation), are of no value to others or cannot be correlated with other tests results or data requirements. A more direct system is required for the Army to understand the effects of smoke and to learn to survive and even utilize smoke.

During the summer of 1976, several efforts were initiated within the Army to meet the needs of the entire smoke situation. One, which specifically concerned testing, was started in early June by a U.S. Army Materiel Development and Readiness Command (DARCOM) tasking message, which required a variety of agencies to try to determine test requirements, to report test plans, and to identify testing resources.

Also, the Harry Diamond Laboratories (HDL) was asked to coordinate with the U.S. Army Training and Doctrine Command (TRADOC) and produce an overall plan for tests. Almost simultaneously, activity was begun in the testing area by the newly designated Project Manager (PM) for Smoke. Although the new PM Office would not be formally established until August 1976, and its operational budget not available until FY77, the designated PM recognized the difficulties in the testing area and was attempting to begin operation with whatever resources were at hand. One available resource was the HDL team responding to the DARCOM order. Thus, as HDL carried out its assignment, close coordination was maintained with the PM Office, and a mutual testing philosophy was evolved. This philosophy, which includes a testing approach as well as the concept of a testing structure, will be discussed in this report and constitutes the "plan for tests."

Coordination of this plan with TRADOC was accomplished by the interaction of the PM Office and the HDL team with the Combined Arms Combat Developments Activity (CACDA) of the Combined Arms Center (CAC). That activity, by means of a letter from the Deputy Chief of Staff for Combat Developments, was established in late July 1976 as the "central directional authority for smoke and flame concepts" within TRADOC. Therefore, CACDA has reviewed and influenced this report and generally concurs with the plan for tests, including the role assigned to it in the structure concept.

The final introductory point to be noted is that, in a general sense, a plan for tests should include both the technology (i.e., what data are obtained from what test with what accuracy and how) and the structure (i.e., through what process and with what facilities test and evaluation will be performed) of the Army's overall testing capability. Unfortunately, the magnitude of the problem and the limited scope of HDL's effort is such that this report must deal primarily with the Army's test structure, although some discussion will be given on instrumentation and modeling techniques. The identification of the structure is, however, an important first step to be followed by CACDA and the PM, forging an efficient and smoothly functioning system of the many elements which make up the structure. Part of the structure's own goals will of course be the full development of the required testing technology under the leadership of the PM Office.

2. PROPOSED STRUCTURE

2.1 Goals and Purpose of Structure

Before identifying a structure within the Army for smoke testing, it is important to establish the overall goal of such a unit. Clearly, that goal should be to be able to assess the effectiveness of

smoke and systems in smoke on the battlefield. Though simply stated, achieving such a goal will require great technical effort, as well as an organization which clearly understands the importance of interrelations of the many facets of a battlefield situation. Understanding these facets is essential to knowing what the term "effectiveness" includes and what testing capabilities are required of the structure.

As the tone of the previous discussion implies the smoke-testing structure must take a very broad view of its obligation to meet the Army's needs. This obligation includes the ability to support operational as well as developmental tests, and to recognize the relations between the two. This position follows the recent trend within the Army to combine development and operational tests where possible, but for testing in smoke, a comprehensive approach is imperative. This is necessary because the use of smoke on the battlefield generally affects all aspects of the engagement, including weapons performance, mobility, logistics, command and control, and human behavior. The only one of these aspects to be explored to date has been weapons performance, since the development community has tested some specific devices operating through (but not in) some smokes. These tests are of course valuable and provide technical data to the developers. These tests do not, however, answer the questions of how effective the systems are in smoked environments or how the smoke may be used effectively. These questions cannot be answered until the performance data are integrated into an evaluation which includes smoke performance data for all other aspects of the battlefield, including tactical and training considerations. At the same time tactics and training requirements cannot be developed without the performance data. In addition, the overall assessment of tactics or any battlefield function in smoke, including hardware performance, must by necessity be made through the use of appropriate force-on-force computer models backed by field operations for the verification and demonstration of principles and results. The necessity of using models is dictated by several considerations. The primary one is economy: field tests are too costly to study all variations of concepts or design parameters, while modeling can do so affordably. An additional consideration is credibility. That is, the results obtained from a validated model of a complicated, but standardized, smoke scenario are less susceptible to the biases or other shortcomings of human judgement. This statement is not meant to imply that human judgement has no place in the evaluation process, particularly in operational matters. Modeling only provides inputs to sound military or technical judgements and, of course, the technical and tactical thinking of the Army must not be driven or limited by its modeling capabilities. The models must be supported and constantly updated by input data from a variety of specific field and laboratory tests as well as submodels (which themselves require testing for data and verification).

It should be evident from even this brief discussion that any evaluation process (and, in fact, the process by which the Army will learn to effectively operate in and utilize smoke) must be founded upon an extensive network of test facilities. Each element in this network must understand its dependence on and obligation to every other element, as well as the direction of the overall Army goals and needs. These individual facilities, combined with leadership provided by the focal points at CACDA and the PM Office, make up the test structure.

Clearly, considerable technical and organizational effort will be required to produce, from the many diverse Army resources, an efficient structure which can take any device or concept as an input and produce an accurate effectiveness assessment as an output. In providing this capability, the structure will also be obligated to fulfill many other important needs which are not currently being addressed in any organized manner. These other tasks include setting standards and goals in smoke testing technology, preventing duplication of effort within the Department of Defense (DoD), providing up-to-date threat assessments, exploiting foreign technology, and dealing with the medical considerations of training and testing in smoke. In addition, the structure can initiate research in smoke testing to meet existing needs and in anticipation of the test requirements of future Army systems or concepts.

To summarize, the structure advocated here represents a formal system within the Army which can deal with all the complexities and subtleties of "testing in smoke." This ability includes recognizing the strong interrelation between operational and developmental (or "tactical and technical") considerations and utilizes a comprehensive approach to assessing the effectiveness of smoke or a system in smoke on the battlefield. In addition to the obvious benefit of meeting the Army's need for a meaningful approach to smoke testing, the structure can also produce very real economic benefits by eliminating duplication of effort (both in the establishment of testing technology and on meeting the needs of "tactical or technical" developers) and by insuring maximum data return from every test conducted by the Army.

At this point some very obvious questions arise. In particular, who will undertake the organizational burden for the structure and who will be included in it? These questions, as well as those about the needs and functioning of the structure itself, will be addressed in the remainder of this chapter.

2.2 Organization and Scope of Structure

2.2.1 Leadership

The starting point for the definition of the structure's organization is its leadership. As was suggested earlier in this report, the leadership for the developmental (or "technical") aspects of the structure will be provided by the Smoke PM. This responsibility is clearly within his charter and the PM has indicated that his office will take an active and aggressive position in testing smoke and systems in smoke. There are, of course, other candidates within the Army for this leadership role, but none possesses the clear authority or unique attributes of the PM Office. These attributes, which will ultimately include financial resources and a comprehensive overview of smoke technology along with the associated corporate memory, leave little room for debate in the matter.

Leadership for the operational side of the structure will be provided by CACDA. Since the specific group assigned to this task is quite new and does not posses the well-defined operational modes and resources of a PM Office, the group may encounter some special problems in assuming this leadership role. In addition, the group is currently developing its methods of operation and defining its own needs. However, the specific assignment of responsibility and the response of the group at CACDA are themselves much needed steps towards meeting the Army's needs, especially since that group can interface with the PM Office to establish a course of action and to begin operations.

2.2.2 Scope of Testing and of Structure

To consider the scope of the structure, the scope of testing (i.e., the considerations to be included and the mechanisms for obtaining data and arriving at conclusions) for "effectiveness assessment" must first be defined. Obviously, each aspect of the engagement (e.g., weapons performance, mobility, etc.) that must be addressed by the structure has a scope of its own, many of which overlap with others. Since this report was generated by those primarily concerned with systems development, weapon systems performance is the only function which can be intelligently addressed in detail here. Although the discussion to follow will therefore be limited to that function, it will be pointed out that the weapons effectiveness assessment overlaps with the requirements for evaluating the effect of smoke upon other battlefield functions. It will be left to the operational community to define the scope of effectiveness assessment for these other functions.

Two viewpoints which are inherent to the developmental aspect of the structure and which expand the scope of weapons effectiveness assessment should now be stated. These follow.

(a) The preliminary definition of smoke given earlier must be expanded to natural aerosols and to specifically include an environment termed "incidental smoke and dust."

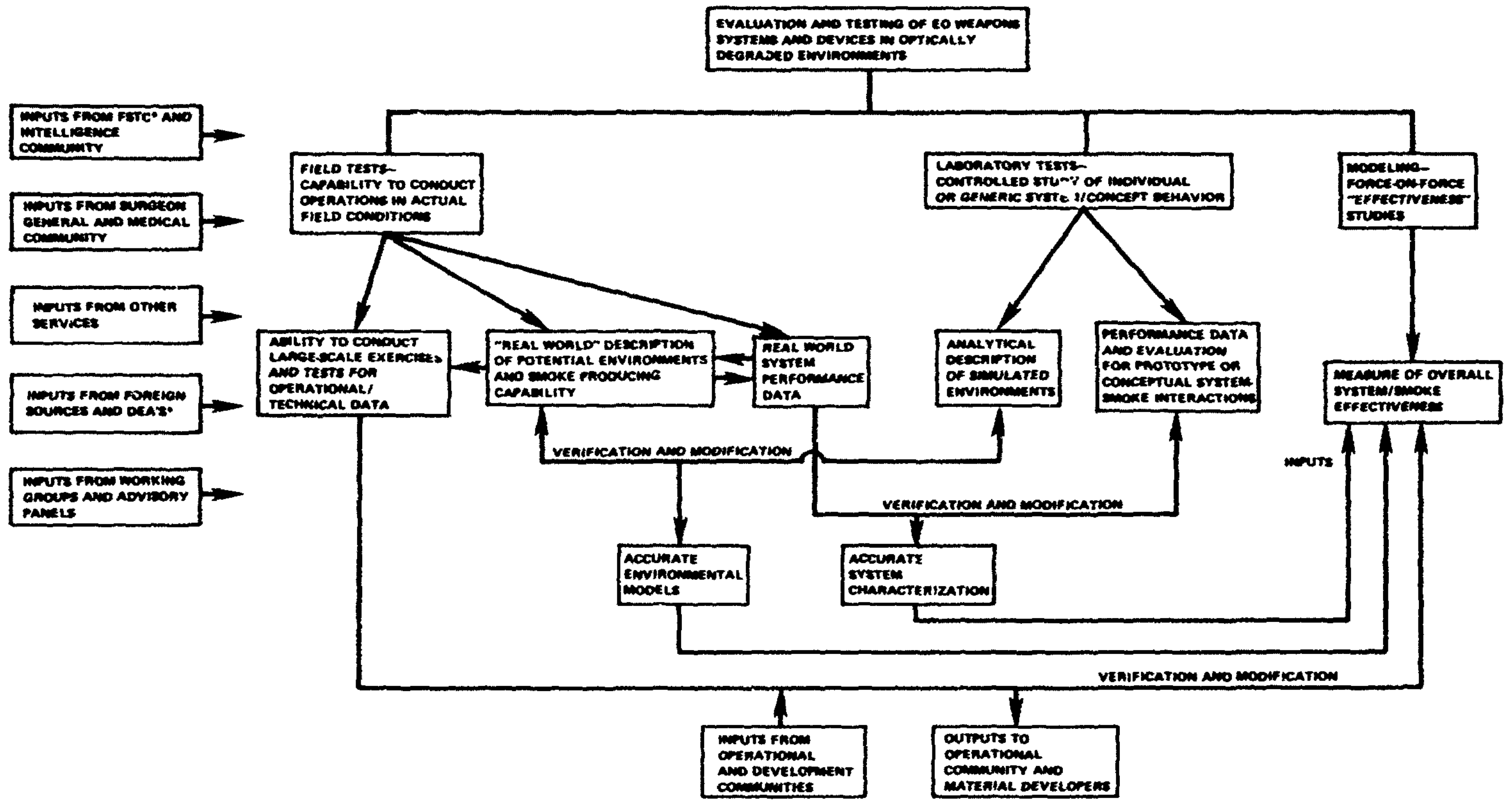
(b) The expertise and resources of the test structure should be utilized at the earliest possible phase of the hardware development cycle.

The motivation for including these factors within a smoke testing philosophy is quite simple. With respect to viewpoint "a," the effects of natural and incidental* aerosols can be so similar to that of smoke that they cannot be ignored in assessing effectiveness. In addition, the effects of these types of "smoke" are not now being formally addressed by the Army† and the structure will be equipped to undertake the task. With respect to viewpoint "b," it is advantageous to utilize the expertise of the structure before a system is developed to the point where countering the effects of smoke is a costly and unpleasant task. In addition, developers, even at the exploratory level, would welcome accurate technical guidance concerning the environment in which their products must operate. The structure will be equipped to provide this guidance in the most useful forms of analytical descriptions and simulation facilities.

When these two viewpoints are taken into consideration one can, after some deliberation, define the scope of testing for weapons effectiveness assessment. One version of this scope, constructed at a recent meeting of representatives from HDL, U.S. Army Material Systems Analysis Activity (AMSAA), Ballistics Research Laboratory (BRL), U.S. Army Test and Evaluation Command (TECOM), Edgewood Arsenal (EA), and the PM Office, is illustrated in figures 1 through 4.

**Incidental smoke and dust are loosely defined as that smoke and dust generated by munitions, systems, or actions not specifically employed for the production of an obscurant. Examples include smoke from battlefield fires, the dust cloud which sometimes engulfs a tank when the main gun is fired, and smoke produced by the detonation of high explosive rounds.*

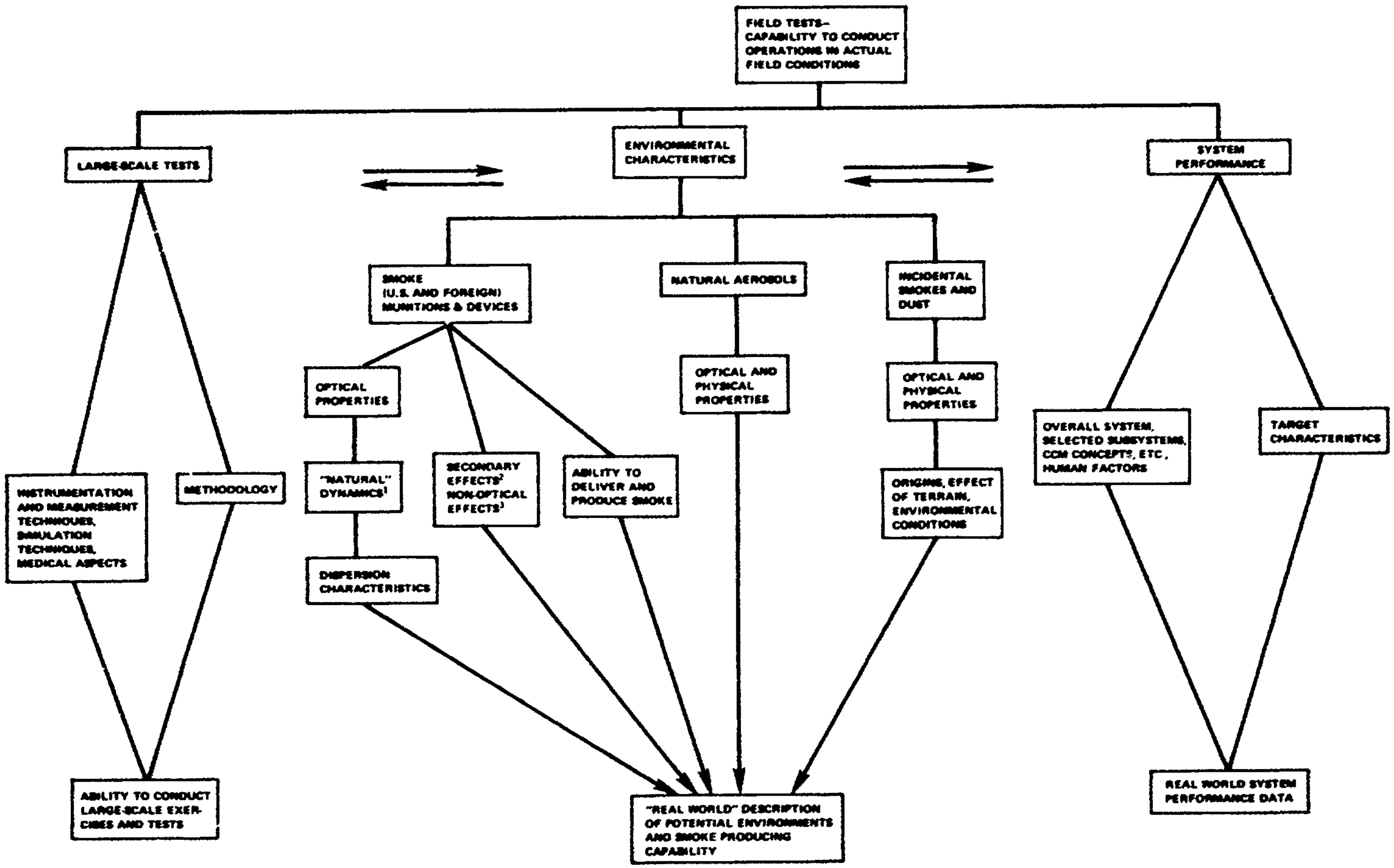
†*This statement is not entirely correct for the case of natural aerosols. A recent HDL study, Phase I - Reduced Visibility Assessment to Director of Battlefield Systems Integration, has identified the problem. Improved atmospheric and meteorological data are currently being sought in several very active DoD programs. These programs should not be isolated from the Army smoke program and may ultimately become that part of the test structure dealing with natural aerosols.*



*FSTC: FOREIGN SCIENCE AND TECHNOLOGY CENTER

DEA: DATA EXCHANGE AGREEMENT

Figure 1. Scope of EO system-smoke interaction testing.



[1] NATURAL DYNAMICS. THE CHEMICAL AND PHYSICAL BEHAVIOR OF THE SMOKE IN THE OPEN ATMOSPHERE

[2] SECONDARY EFFECTS. EFFECTS OF A SMOKE MUNITION OTHER THAN PRODUCING SMOKE, e.g., BLAST, THERMAL INCENDIARY ETC

[3] NON-OPTICAL EFFECTS. EFFECTS OF SMOKE ON OTHER THAN THE OPTICAL PERFORMANCE ASPECTS OF HARDWARE, e.g., DEGRADATION OF AIR-BREATHING ENGINES, CHEMICAL INTERACTION BETWEEN SMOKE AND MATERIALS USED IN HARDWARE ETC

Figure 2. Required areas of activity to develop desired field test capability.

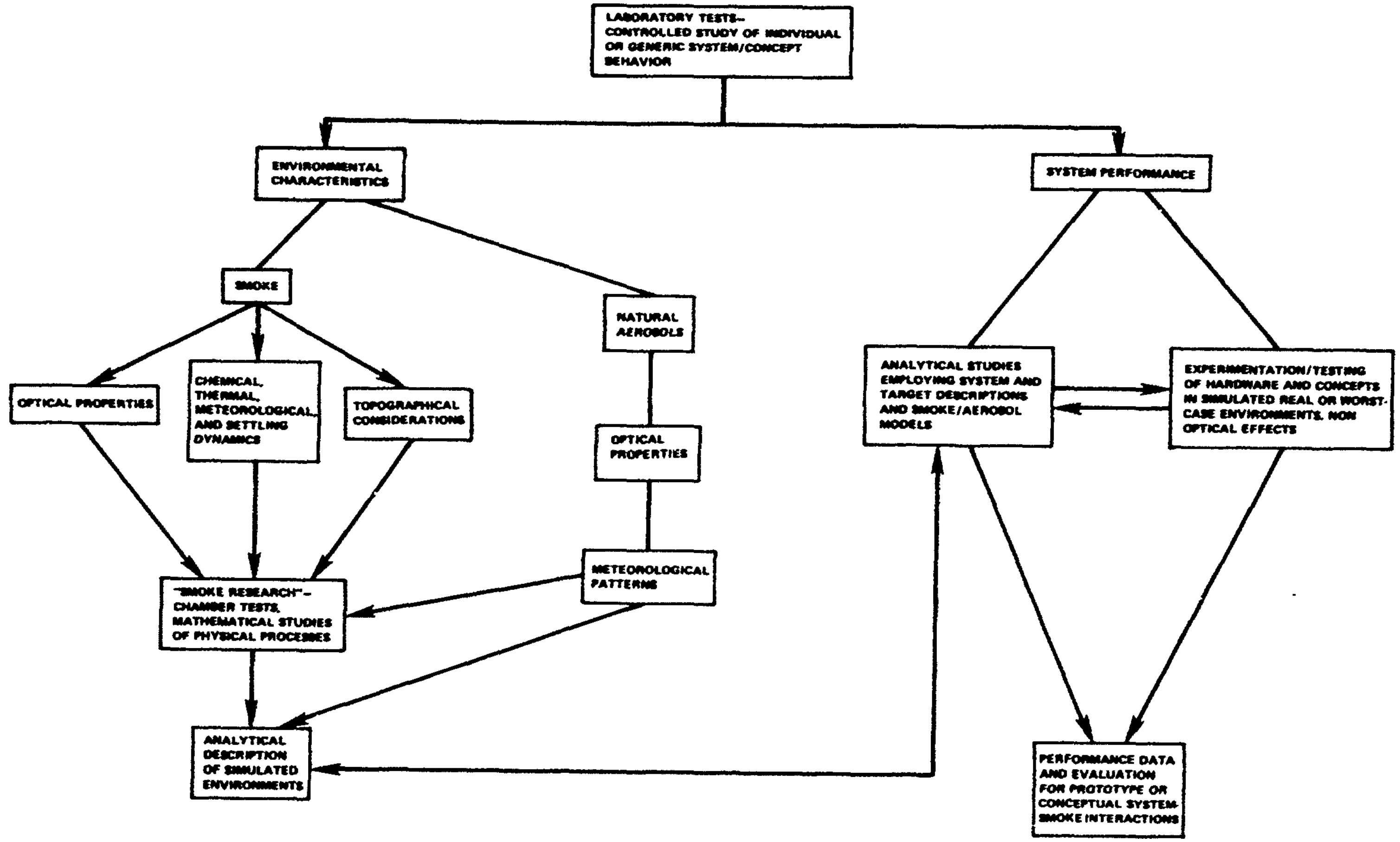


Figure 3. Required areas of activity to develop desired laboratory test capabilities.

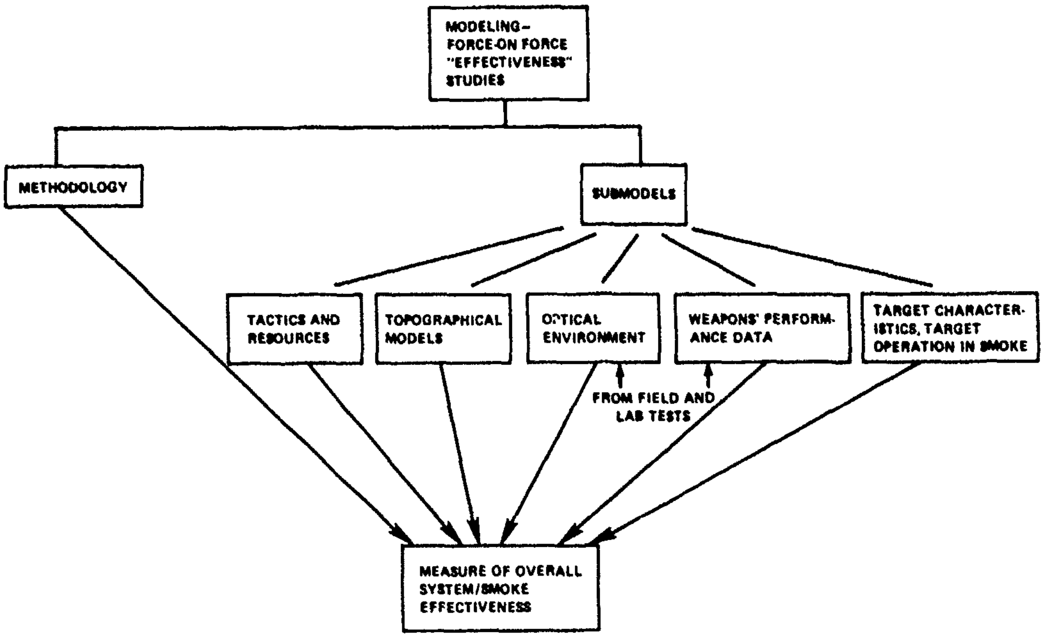


Figure 4. Required areas of activity to develop desired modeling capability.

Figure 1, an overview, defines the major test categories, the desired result or capabilities in each category, and the desired result produced by interactions between the categories. In this figure, the term "optically degraded environments" is employed, because of the previously discussed concern with natural and incidental aerosols. Also, the wording specifically identifies "EO weapon systems and devices." This wording is used because optical wavelength systems are most affected by aerosols and are of prime concern to the Army right now. This terminology is not, however, intended to be restrictive, since the structure is certainly concerned with testing such "nonweapons" as the human eye and smoke generators.* This point is perhaps illustrated more clearly in figures 2 through 4, which show the lines of inquiry to be followed in each category so that the desired capabilities are achieved.

**Obviously, the testing of smoke generators or munitions and the testing of EO systems are two sides of the same process. That is, the effectiveness of a smoke-producing device cannot ultimately be assessed except in terms of its effects upon EO systems.*

Though it is not necessary here to discuss these figures in detail, the commonality of some topics in each category with topics of importance for evaluating the impact of smoke on other battlefield functions can be indicated.

For field tests, the most obvious capability common to the needs of operational testing is the ability to conduct large-scale tests. Tests of this type, in which developers may be seeking verification or input data (concerning system-operator interaction as well as target behavior in smoke) for their hardware or models, can be the same tests (and for some points the same data) in which the operational community will study other battlefield functions in smoke. In addition, the smoke training and experience levels of participating personnel will have an impact on the results of any systems or tactics test. Thus, the structure will have some direct concern with troop training. Its expertise in conducting large-scale tests can be applied to the development and execution of training requirements, particularly for dealing with the toxicity aspects and for producing valid battlefield simulations when the normal delivery modes for certain munitions are prohibited.

Modeling is another important area common to weapons effectiveness assessment and study of other battlefield functions. As indicated previously, modeling is in one sense a "complete" test, since it offers a mechanism for properly weighing the various factors in a battlefield scenario.

Most of these factors are operational and include the tactics and execution of all battlefield functions by both sides in an encounter. It is therefore clear that the models used for assessing the effectiveness of a weapons system or of a smoke munition must be very similar to one used for studying tactics, or logistics problems, or any operational consideration. The difference among various models would be one of emphasis or degree of refinement with respect to certain functions. Even with a different emphasis, most models would use many identical submodels. Thus, the model described in figure 4 actually represents one member of a family of models which meet the needs of test structure and which have much in common. The family should be developed cooperatively by the operational and developmental sides of the test structure, with coordinated verification efforts built into the structure's field and laboratory test.

There is little need to continue to point out these common aspects of the weapons testing scope, as they are quite obvious to an interested observer. The final point to be made with respect to figures 1 to 4 is that no claim is made to absolute correctness or authority. It is possible that some aspect of weapons effectiveness assessment has been overlooked or, in some opinions, miscategorized or

that the wording used to describe a desired capability or result inadequately conveys the true intent. These shortcomings are not overly serious, however, as the figures can certainly serve as a starting point for the organization of this aspect of the structure.

Having examined the scope of testing required for the technical side of the structure, and having discussed some of the operational aspects of testing, one may define the scope of the entire test structure. Figure 5 shows the interactive joint leadership, along with the dual tactical and technical nature of the evaluation to be made. The boxes identifying the specific function to be addressed are shown overlapping each other as a simple indication of the interaction of each of these functions. On the tactical side of the structure, the number of functions has been left indeterminate, as it remains for the operational community to fully define its needs. Also, training, though not listed previously as a required battlefield function, is specifically included in figure 5 because of the impact which training levels can have on test results. The required test capabilities for each function also are indicated in figure 5. The requirements are stated specifically only under weapons performance, and in that case the interrelation of the categories is again illustrated by overlapping boxes. Though the required test capabilities for the tactical aspects must be decided upon by the operational community, "field tests" and "modeling" will be the most important categories. These models or field-testing capabilities will, as stated previously, be very similar or identical to some of those listed on the technical side of the structure.

The lowest level in this figure indicates the net result obtained by the Army from its test structure. The result is double sided since the ability to assess smoke effectiveness on the battlefield also provides a mechanism for developing an effective smoke posture. An effective posture means a knowledge of what environments to expect or utilize on the battlefield and the tactics, equipment, and training to successfully create and operate in these environments.

The final point for the scope of the structure concerns the flow of pertinent information from, into, and within the structure. Information from outside sources (some of which were indicated in fig. 1 and again in fig. 5) must flow into the structure through its leadership. The leadership must also assume responsibility for reporting official positions or test results to interested groups outside the structure (such as the development, intelligence, or foreign communities). The leadership must also interact between the various elements of the structure in reporting results as well as needs and problem areas. At this time it is presumed that the PM Office, because of its total involvment in smoke technology, will assume the main burden of these responsibilities.

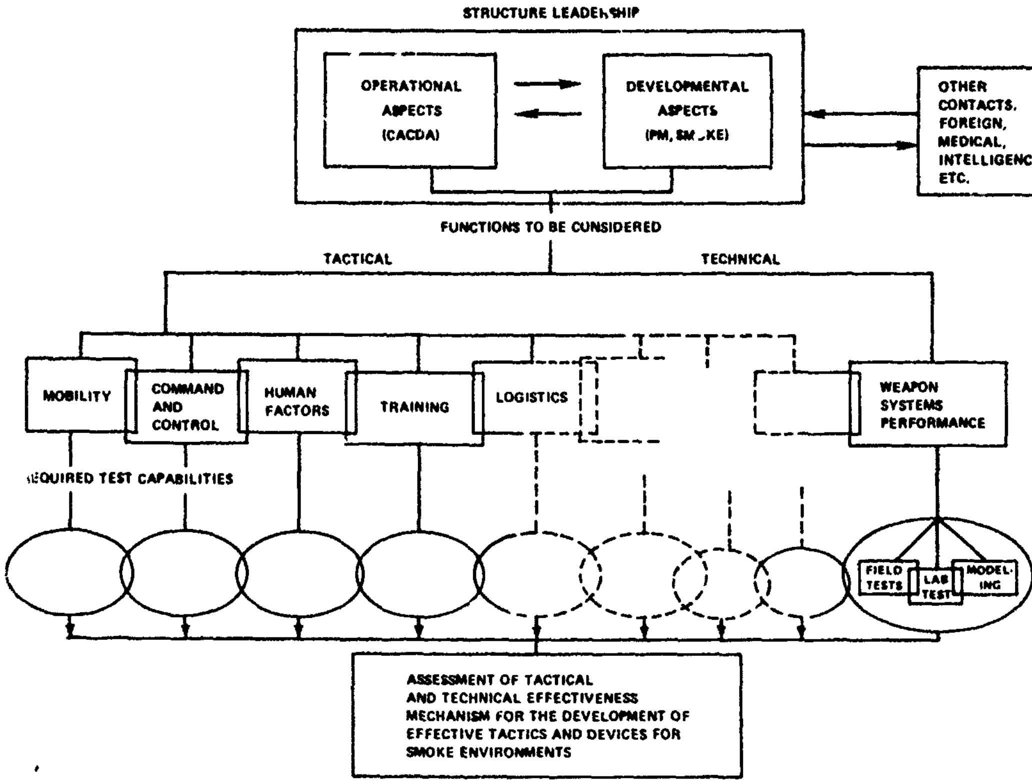


Figure 5. Scope of test structure.

The previous discussion is not meant to imply that the structure elements will interface only with the leadership. Such an attitude would not be workable or even desirable. Because of the magnitude of the smoke testing problem, the various resources within the Army must maintain to a large degree their current independence and pursuit of individual programs. The role of the leadership is to bring some organization onto the scene and create a formalized mechanism for guaranteeing that all problems are addressed and that maximum benefit and progress are obtained from the individual programs. As an example, consider the Smoke/Aerosol Working Group of the Joint Technical Coordinating Group (JTCG). As this group has independent resources and programs directly concerned with smoke technology and smoke-system interactions, it must be considered a resource to be included in the structure. Some of this group's programs may be best implemented at

other elements of the structure, and the results of these programs may be of direct value to the structure. At the same time, this working group is a tri-service organization and thereby represents a formal communication channel to the Navy and Air Force for smoke technology and information interchanges. By placing members of the structure's leadership organizations in this working group, the group's programs become formally coordinated with the entire smoke community, and the leadership fulfills its role. The group does not, however, give up its own identity or independent programs, nor does it forego its responsibilities to or lines of communication with the other services. In this case, the working group is a member of the structure, but at the same time it is also a user, as well as the leadership's formal link to the other services. Such multifaceted roles for structure elements are both necessary and efficient.

2.2.3 Functioning of Structure

Perhaps a reasonable starting point for this discussion is the identification of those to be served by the structure. One simple breakdown is that the structure serves the Army, the DoD, and itself.

The structure users within the Army can again be classed as either technical or tactical. The structure's function with respect to the technical community is to insure that the impact of smoke upon the developer's system is considered and to carry out the effectiveness assessment in conjunction with the developer. For systems currently in advanced development, the specific task of the structure leadership will be to contribute to existing test plans and to provide the best recommendations possible (concerning test methodology, technology, and facilities) without yet having reviewed and evaluated the structure's own capabilities. These contributions should be made to both operational and developmental test plans.

For those systems at earlier stages of development or for future systems, the structure's function will include guaranteeing a very early smoke awareness by the developer and providing technical support in the form of threat assessment, analytic smoke models, and test or simulation facilities. This support would include also a data bank of prior tests and results which may ultimately provide a means for eliminating some aspects of smoke testing for systems or subsystems similar to hardware previously evaluated.

In view of these points, it seems clear that an additional task of the structure will be to inform the Army of smoke threats and capabilities and of the structure's resources for supporting both tactical and technical developers. One important mechanism to help the structure leadership to carry out this task could be for them to organize and host an annual or biennial Smoke Symposium. Topics for presentation at the symposium would include current and projected threat analyses, current and projected capabilities for U.S. smoke munitions, the state of the art in modeling, simulation, and testing technology, and some discussion by the tactical side of the structure on the possible impact of smoke on tactics, training, and operational testing methodology and plans. The audience at the symposium should not be limited to the smoke and EO systems communities, but must include maximum representation from the DoD as a whole. This audience should be educated to the level where each member can estimate potential problems created by smoke in his specific area of interest. The symposium approach would thereby help to assure a continuing consciousness of smoke by the DoD and at the same time would help to introduce to the audience the organization and capabilities of the structure which can support their potential test needs. This point is particularly relevant for the first symposium, which, in fact, is already being planned by the PM Office.

Another innovation which the test structure could offer is a "smoke week" for hardware developers. At this event, system developers would be invited to bring their items to a fully instrumented test site for operation in or through a variety of smokes. This procedure would be particularly valuable today, when there are several development programs with prototype EO systems available which have never undergone testing in a fully instrumented smoke environment. The concept of a smoke week, though certainly not a comprehensive smoke testing process, does represent a low-cost approach to obtaining quality technical data by systems developers. The merits of this concept will be pursued further by the PM Office as the structure's organization proceeds.

The discussion so far has primarily been concerned with the functioning of the structure with respect to the technical side of the Army's needs. In previous sections of this report a philosophy or approach for considering the operational aspects of the evaluation of smoke or system effectiveness was presented. It was not made clear in those discussions exactly how the structure would insure that relevant information is obtained (i.e., who orders that tests be conducted) and utilized (i.e., who receives the test results) by tactics and training

developers to the ultimate benefit of field-level users. Of course, it is expected that the leadership of the operational side of the structure will undertake this task, but for reasons stated previously, their specific approach cannot be speculated upon here.

The general method by which the structure serves the Army applies equally well to the DoD as a whole. That is, the structure leadership, through participation on various tri-service committees or panels and through the smoke symposium, must attempt to inform the DoD of potential smoke threats or benefits. The leadership could then, in response to specific inquiries, direct DoD users through the appropriate facilities of the structure.

The final point to be discussed here is the mechanism by which the structure will serve itself. Some tasks relating to this point, such as initiating research in smoke testing technology to meet current and anticipated needs, have already been mentioned. These programs will be conducted by members of the structure itself and the results, through the leadership, will be distributed and adopted throughout the structure. Also, because of the "overview" position of the leadership, development or operational smoke tests conducted by the structure can be capitalized upon to serve as vehicles for simultaneously conducting testing technology research. The results of these types of efforts are that the structure serves itself by efficiently maintaining a useable and up-to-date test and evaluation capability. This assignment does not necessarily imply an ever-expanding test structure. As stated previously, it is expected that the corporate experience and data base of the structure will ultimately lead to less smoke testing, but a greater ability to meet the Army's needs.

2.2.4 Implementation and Cost of Structure

The procedure for implementing the concept of a test structure into a working entity seems to be relatively straightforward, though not necessarily a simple matter. The task has been made immeasurably easier by the creation of a smoke PM Office to provide the needed leadership.

The first step is for the leadership to establish its own concept of what the structure will be and how it will function. This report, though not completely firm on many points, has been produced in coordination with the PM Office and represents a working guide for the completion of that first step. The report also carries the implementation somewhat further by including a preliminary survey of the Army's resources and by outlining the testing approach and interrelations for the development and operational aspects of the structure.

Perhaps one of the next steps for the PM Office is to solidify relations and testing approaches with the leadership of the operational side of the structure. This step can be followed by the difficult task, which must ultimately be faced, of performing a detailed technical evaluation of existing resources. A great many agencies posses some capability for some aspects of smoke testing. In many cases these capabilities bear the same labels, such as force-on-force models, smoke models, field-test facility, and test chambers. It will be the task of the leadership to determine the role and applicability of each of these capabilities to the needs of the structure. The results of this evaluation should be extensive. First, the leadership can produce an official position on exactly where and with what degree of quality each aspect of the testing scope will be addressed within the structure. This result will establish the basic constituency of the structure, as well as eliminate the need for evaluating facilities by every developer requiring testing in smoke. The evaluation may also identify duplication and should at least make the smoke community conscious of similarities or differences among programs bearing the same labels. These differences may be quite significant, and it is expected that the structure will require multiple facilities for addressing each test category. For example, some aspects of field testing all or certain systems may be best handled at Dugway Proving Grounds (DPG), while other aspects or types of field tests may best be conducted by the Office of the Test Director (OTD) or in a joint operation. Thus, both organizations must be included within the structure, but the applicability and limitations of their capabilities must be clearly understood both by the organizations and by the structure leadership.

Another result of the evaluations is that problem areas or weaknesses in the Army's testing capability will be identified. Efforts by individual members of the smoke community to address these problems should also surface in the evaluation process, and the leadership can then organize these efforts into a concerted attack on the problems. This process not only will produce more efficient programs, but also may identify problems which are not currently being addressed.

This evaluation and assignment of roles within the structure may be viewed with some trepidation by current elements of the smoke community. There is no basis for this view, as the formation of the structure will be to their benefit as well as to the Army's as a whole.

In the first place, it is likely that all existing test facility posses some capability which make their inclusion in the structure imperative. An affiliation with the structure therefore guarantees that no element will be bypassed in future test programs.

In addition, each element does have its own programs and funding sources which currently involve it in smoke technology. The recognition of similarities in programs and goals and the coordination of efforts can only improve the efficiency and performance of each element in these individual projects. The structure may, in fact, provide some elements with a needed aspect of smoke technology which they do not posses or desire to develop. After all, members of the structure are also users of the structure. These comments may be particularly applicable to those elements, such as Army Missile Command (MICOM) and the Night Vision Laboratory (NVL), which in the past have acted as the main smoke technology and testing arms of specific hardware developers.

Actually conducting the technical evaluations will be difficult. The mechanism for this operation in some cases, particularly in examining the variety of smoke and battlefield simulation computer models, will have to be group meetings of technical personnel from the various agencies. Through technical briefings and working sessions at these meetings, the modeling workers as a group can conclude which models should be employed by the structure for its various applications, as well as chart a coordinated direction for the future of their individual programs.

For other test areas, such as field testing, the evaluation can perhaps be a simpler process in which the PM Office and the testing facilities easily see differences in intended applications and the ways in which the various facilities complement each other to form the overall testing capability. Regardless of the mechanisms, however, the evaluations must be undertaken so that the leadership can properly guide the structure and provide users with a meaningful test process which is free of conflicting or confusing attitudes and technical or administrative bickering on the part of the testers.

The total cost for establishing and maintaining an Army test structure is well beyond the scope of this report for a variety of reasons. One important reason is that the operating costs of all facilities which may ultimately be part of the test structure are unknown. Another reason is the very broad view of the scope of smoke testing taken in this report. This view would make it impossible in some types of future smoke "tests" to separate costs for the test from costs for developing test technology or for advancing some other aspect of smoke technology. An additional unknown factor in any current cost estimation is the degree of effort required to bring the Army's existing test capability up to the desired level. Some measure of this factor will be obtained through the technical evaluation.

An important factor to be remembered here is that a great deal of money will be spent by the Army for smoke testing and test technology regardless of the role played by the PM Office or CACDA, its counterpart in the operational community. One purpose of their organizing the proposed structure is to have this money spent efficiently. The cost to the leadership to accomplish this end will be relatively small. Again confining the discussion to the development side of the structure, a thorough managerial effort by the PM Office could perhaps be conducted with four full-time workers at a cost of about $250,000 for the first year. This figure includes expenses for the smoke symposium but not for those costs incurred by the various agencies participating in the symposium or the technical evaluation process. In addition, this managerial team requires funds to initiate programs to fully develop the structure's required capabilities. The PM Office cannot, obviously, fund all these efforts. However, the team should have enough funds to support selected programs at various agencies and thereby influence the direction of programs and resources internal to those agencies. By this mechanism, along with being the recognized interface between users and testers, the PM Office can view and guide the development of testing technology within the Army. Exactly how much money is required to set existing resources in motion towards the technical goals of the structure is dependent upon many variables, including the magnitude of the problems to be solved and the rate of progress desired. Even though these factors will not be clarified until technical evaluations are conducted, it is clear that in view of the current priority position of smoke and the obvious technical problems, a budget of less than $250,000 for these supporting programs would greatly impede the development of a meaningful and capable test structure.

From the previous discussion it is apparent that a burden of $500,000 must be assumed by the PM Office, for FY77, to begin to meet the Army's testing needs. This initial investment and continuing support through the PM Office can guide the much greater Army-wide spending efficiently and produce the total capability which the Army requires with respect to smoke.

3. RESOURCES FOR EFFECTIVENESS ASSESSMENT

3.1 Introduction

In this section a brief survey of existing resources is presented along with some discussion of the technical aspects of smoke testing.

The source material for this survey consists of published literature, the responses to the DARCOM inquiry described in section 1, and in most cases personel visits to the facilities or discussions with their technical personnel by the HDL team.

The survey is not a complete one since there are a rather large number of agencies, offices, groups, or panels which have expressed some interest or capability relative to smoke testing. Some indication of this number can perhaps be obtained from a recent study[1] which dealt with the creation of a technical data center for smoke. In that document, an estimation of projected levels of activity in smoke shows 30 organizations (1 Navy, 3 Air Force, and 26 Army, including 8 project managers) in the "increased" or "active" categories. This does not mean that each of these 30 organizations is a testing resource. On the other hand, the estimation sometimes listed only a command (such as TECOM) and not individual facilities within that command, or omitted a class of organizations (such as advisory panels or working groups), and did not include private industry. Clearly, the surveying of all possible testing resources was beyond the scope of the HDL task, and so only the more active facilities are discussed in this report.

The major omissions in the HDL survey are the resources of the private sector and of the Army's operational test community. The operational test community would be more appropriately surveyed under CACDA's guidance. This report therefore lists only a few of these facilities with a simple indication of the nature of their operation. The private sector is omitted completely (except in mentioning contractors for specific projects), in keeping with HDL's assignments and with the fact that it would be inappropriate to discuss the resources of any single company if all pertinent companies could be not be covered. This does not mean that industry's resources for smoke testing should be excluded from the Army's test structure. It will lie with the PM Office and the governmental members of the structure to decide when and how to best utilize the private sector.

It should also be noted that there are several special organizations within the Army which are not covered here but which initiate or support efforts relevant to this survey. For example, the Battlefield System Integration Directorate (BSI), a segment of DARCOM headquarters, is currently concerned with weapon performance under low

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[1]*Requirements and Recommendations for a Smoke Technical Data Center, Analytics Inc. (13 December 1975) submitted to the Smoke Program Office, Edgewood Arsenal, under contract DAAA1576C0005.*

visibility conditions and is supporting efforts to evaluate the problem and to include low visibility considerations in battlefield models.[2] An additional example is the Army Research Office (ARO), which sponsors a great deal of relevant research at various universities. Coordination with such organizations will again be an activity of the PM Office.

Finally it should be pointed out that, in response to the DARCOM tasking message, TECOM has prepared a report which reviews general capabilities of existing resources. This section is closely related to that report, and therefore the TECOM report (less its appendices) is reproduced in appendix A. The material in this section is, however, a more detailed and somewhat technical coverage of the resources.

3.2 Survey of Resources

3.2.1 U.S. Army Test and Evaluation Command (TECOM)

The mission for development and acceptance testing within DARCOM lies with TECOM and in that role TECOM has a primary responsibility in testing methodology. In its recent report (app A) TECOM resources are described, and the requirements both for EO systems performance and for Developmental Testing (DT) and Operational Testing (OT) of smokes are addressed. TECOM maintains a network of proving grounds, several of which have some capability for smoke testing. Recently, Dugway Proving Ground (DPG) has been designated as the testing center for characterizing smoke and for measurements of EO system performance in smoke and has therefore been tasked to determine the required methodology. The capability at DPG is detailed below, followed by a brief description of a planned facility at TECOM's Army Electronic Proving Ground.

3.2.1.1 Capability at Dugway Proving Ground

As a chemical-biological-radiological (CBR) center, DPG has long been involved in aerosol characterization. The Anderson Sampler was developed there and is still a mainstay of aerosol instrumentation. The DPG researchers are well along in the development of an excellent capability in the characterization of smoke.

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[2] *William H. Pepper, Limited Visibility Operations Assessment (Phases I and II), Harry Diamond Laboratories TM-77-16 (December 1977). (SECRET NO FOREIGN DISSEMINATION)*

In response to the methodology determination task, an initial test was conducted by DPG in August 1976 using white phosphorus (WP) and hexachloroethan (HC) live firing. During the test, EO equipment also was tested by a visiting team from the Office of Missile Electronic Warfare (OMEW). The DPG testing program will continue in an effort to improve testing instrumentation and procedure. Specific facilities at DPG are discussed in the following sections.

3.2.1.2 Test and Calibration Instruments

DPG possesses the full array of standard electronic and optical instrumentation. Of particular relevance here is DPG's unique capability for the collection and measurement of aerosol particles. Interest in the instrumentation used in this process is such that a detailed description is merited and is given below.

Chemical Impinger (CI).--This device is a test tube with an inlet tube and critical orifice so arranged that the aerosol particles are accelerated to high velocity in the orifice, and all impinge on the bottom of the tube. The CI has a side draw tube, and air is drawn through at a standard rate (6 liter/min). The instrument measures total dosage during the time the air supply is on. The CI is sensitive to wind velocity but has proven reliable for wind velocities of 4 to 10 mph. After collection the tube is sealed and later analyzed for total phosphoric acid (for WP smoke) or for ZnCl (for HC smoke).

The CI is an inexpensive device, costing about $0.50 per assembly. Another device, the All Glass Impinger (AGP), is commercially available but costs about $20 each. DPG has found the CI device to be generally satisfactory.

Modified Anderson Sampler.--This instrument was developed at DPG and consists of nine impactor stages. Each stage has an array of holes (critical orifices) and an impactor plate. The first stage has larger holes for a low critical orifice velocity. Only the largest particles have sufficient momentum to leave the airstream and impact on the plate. All the smaller particles are carried with the airstream to the next stage. The second stage has an array of smaller holes for a higher critical orifice velocity. At that velocity somewhat smaller particles will have sufficient momentum to leave the airstream and reach the impactor plate. Successive stages have smaller holes for higher orifice velocity and select out successively smaller particles.

The total material which is deposited on each impact plate is determined by chemical analysis, and suitable procedures have been developed for phosphoric acid and ZnCl, the end products of WP and

HC smoke. Paraffin impactor plates are prepared, and a cleaning and drying process has been developed which has proven satisfactory for the two smokes considered. For the recent test several nine-stage Anderson Samplers were used, and the chemical analysis was completed (by a chemist and an assistant) within a week. Analysis could be done more accurately and efficiently with a robot chemist, a device which is used at DPG and will be available on a loan basis for future tests.

Present analysis methods are satisfactory for WP and HC smoke. So far, fog oil and diesel oil have not been used. Additional analytical methods would have to be developed for oil aerosols; i.e., a paraffin impactor surface would not be used because of its solubility in oil. No major problem is foreseen in instrumenting for oil smokes.

Climet Counter.--The Climet instrument is a counter which operates on an entirely different principle than the impactors. A sample of aerosol is drawn into a small chamber, usually diluted with filtered air, and passed through a focused light beam. The light is then scattered to a photodetector. The geometry is such that only one particle at a time is in the scattering region, and the amplitude of the scattered radiation pulse provides a measure of the particle size. The logic and presentation then provide a particle-size distribution for the aerosol.

There are a variety of problems inherent to this type of instrument. Dilution, collisions with the walls, pressure, and temperature changes can all alter the particle-size distribution. The geometric design of such instruments must be done with great care to prevent adverse effects. The angular distribution of scattered light is a strong function of particle size, wavelength, and the complex index of refraction.

The Climet Counter minimizes the problems in several ways. Dilution is done in a laminar-flow, coaxial draw tube in such a way that the dilution and the sample do not actually mix. White light is used to average out wavelength effects. Wide-angle elliptical optics are used to minimize the effects of variation in the volume scattering function.

One Climet instrument has been acquired by DPG and the procurement of one or two more is under consideration. The Climet was selected over other counters for the reasons mentioned. One contender in particular, the Knollenberg counter, is a simpler instrument and has performed well in measurement of natural aerosols. However, it is not well suited for the high particle density typical of smoke, and it uses a HeNe laser illuminator which places the Mie* resonance in the

**Some discussion of Mie theory with technical references is given in section 3.4.*

part of the particle-size spectrum that is most significant for smoke, leading to excessive errors. Smoke generally consists of smaller droplets than natural aerosols.

Royco Counter.--The Royco instrument is an older device with a less sophisticated design than the Climet. It uses white light and measures scattering at 90 deg where there is relatively less variation in the volume scattering function. DPG has a Royco instrument which is used primarily in calibration work with the nylon beads rather than with liquid aerosols.

Berglund-Liu Aerosol Generator.--This instrument can generate a monodispersed liquid or solid aerosol for calibration purposes. A stream of water or other liquid solution is forced through an orifice. A piezoelectric driving element is coupled to the plate containing the orifice and introduces modulation into the flow of the liquid stream. The element breaks up the stream in a controlled manner. The droplets pass into a turbulent airstream which disperses them, preventing coagulation. The airstream can be dry, in which case the liquid evaporates, leaving the solid solute as a monodispersed aerosol.

Nylon Beads.--Uniform nylon beads are available in sizes in the submicrometer range from Dow Chemical Co. These beads are certified by the National Bureau of Standards and have an index of refraction about 6 percent higher than that of water. At DPG a slurry of beads and water is atomized into a drying chamber. The dried beads then form an aerosol which is used to calibrate one stage of an Anderson Sampler or other instrument. Concentration is measured above and below the sampler stage while the beam aerosol is drawn through at the specified rate. The change in concentration is a measure of the efficiency of the stage for the given particle size.

3.2.1.3 Modeling

DPG is using a model that describes spatial distribution of concentration of a smoke cloud. A random distribution of wicks (for WP wick rounds) in a circular area dependent on burst height is generated. For a given wick within the pattern and with given meteorological conditions, diffusional growth of the plume is determined. Both wind and wind shear are taken into account. For a given optical path, concentration components from all the wicks are added, giving total concentration along the path as a function of time. This output can then be combined with a value for the extinction coefficient* at the wavelength of interest for the particular smoke (determined by field and chamber measurements) to produce the time variation of transmission along the path.

**The extinction coefficient is defined in section 3.4.*

3.2.1.4 Other Facilities

Firing Grids.--Two field firing-grid facilities are at DPG. These are equipped with upper and lower circular tracks about the impact area. An instrumented vertical grid is mounted on the tracks and can be moved to always be downwind of the impact area. The vertical grid has an array of CI and Anderson Samplers with draw tubes and valves that will sample the smoke cloud providing concentration versus time data. Also, an array of metoerological instruments is on the grid providing detailed meteorological data.

Wind Tunnel.--A small wind tunnel is available at DPG. Smoke can be introduced and instruments calibrated for wind velocity effects.

Test Chamber.--A large test chamber, 30 by 50 ft and 20 ft high (9.1 by 15.2 by 6.1 m) has been constructed at DPG for decontamination studies in support of the CBR program. The chamber features complete containment of contaminants and simulation of a full range of environmental conditions. It is well suited for smoke measurements under controlled test conditions.

3.2.1.5 Planned EO Test Facility at the Army Electronic Proving Ground (AEPG)

The Electromagnetic Environment Test Facility at AEPG, Fort Huachuca, has a mission in evaluation of the electromagnetic compatibility and vulnerability of military electronic devices and systems. In the past these evaluations covered only the radio frequency portion of the electromagnetic spectrum. However, due to the great increase of EO devices and systems in the Army, an EO test facility is being planned.

The primary feature of this facility will be a large test chamber for battlefield simulations. The planned chamber will consist of four parts. The propagation tunnel itself will be 150 ft long (46 m) and 15 by 15 ft (4.6 by 4.6 m) in cross section. The sensor test area will be a room at one end equipped with the necessary supporting services to operate the sensors, including adjacent clean room facilities. The target area will be at the other end of the tunnel and will be equipped with simulated targets and backgrounds. The target area will also be equipped to simulate interfering sources such as lasers, fires, flares, and shell bursts. There will be an Intervening Environmental Simulator in the central region of the tunnel with one or more chambers that can be charged with smoke or aerosol. The facility is scheduled to be in operation by mid-1978. The initial use will be testing of passive sights with the effects of interfering sources being a major concern.

3.2.2 Office of Test Director, Joint Services Electro-Optical Guided Weapons Countermeasures Test Program

This office has the mission of countermeasure testing for EO guided weapons. The agency is tri-service, receiving funds from the Office of the Director of Defense Research and Engineering (DDR&E). Within the Army it appears to have close ties to the U.S. Army Missile Command (MICOM). General capabilities are discussed in appendix A, so only a few points of interest are mentioned here.

The agency has developed a system of instrumentation which is housed in four vans and has the capability of exercising guided weapons of various types. The vans can be moved to operate at various test areas. They have been moved by air but at a cost comparable to that of a major test program. Smoke has played only a small role in prior test programs of the Office of the Test Director (OTD) and they do not have a capability to fully measure the physical characteristics of smoke. The main capability of OTD is a backscatter laser instrument which uses a short pulse Nd-YAG laser and records the backscatter from air and a small aerosol cloud. This device will be discussed in more detail in section 3.4.

3.2.3 The Office of Missile Electronic Warfare (OMEW)

OMEW is an agency of the Army Electronics Research and Development Command (ERADCOM) and has the mission of investigating CM vulnerability for all Army missile weapons. OMEW does not have a smoke-testing capability, but is interested in modeling and sent a team to participate in the recent test at DPG.

OMEW is currently performing a modeling study for the Copperhead PM Office. The program consists of three parts: definition of the threat, impact of smoke on intervisibility, and interaction of smoke and countermeasures.

To define the threat, OMEW expects to issue a report estimating the Soviet threat from the present to 1985. OMEW will develop tactical scenarios or will use scenarios that may be available for use in the intervisibility study.

The intervisibility study will be conducted largely at New Mexico State University and makes use of digitized Fulda Gap terrain data with vegetation overlay. The tactical scenarios specifying attack units and defender locations will be used to identify Copperhead engagement opportunities.

The first two parts of the program are to be finished in six months and will be followed by the evaluation of CM's in a smoke environment.

This modeling effort is part of the Project Manager's response to the threat of smoke and resulting degradation of Copperhead performance. The Project Manager's immediate response (as of April or May 1976) was that tactics must be taken into account in evaluating weapon performance in smoke. The effort at OMEW, paralleling a technical effort at HDL, is the follow-up to develop and evaluate appropriate tactics for Copperhead in a smoke environment.

3.2.4 Edgewood Arsenal (EA)

A primary mission of EA is the development of smoke munitions. They are also active in research with emphasis in new and more effective long-wave screening agents. This work does not fall within the scope of EO equipment performance under operational conditions and so will not be discussed further.

At Frankford Arsenal EA conducts or supports chamber tests and other work in the characteristics of U.S. and foreign smokes which are of immediate EO equipment concern. The Smoke Program Office (SPO) within EA has served in the recent past as an information center on smoke, but that function and many of the SPO personnel have now gone into the Smoke PM Office.

For general information, some EA activities which have a bearing on EO equipment performance are presented here. Some smoke parameters are given which are either based on or extracted from EA data, and listings of recent smoke tests prepared by EA are reproduced in part.

EA is supporting the TECOM effort to establish a smoke testing center at DPG. The recent July/August tests were funded jointly by EA and TECOM and are part of the smoke methodology study undertaken by DPG. The general classes of smoke materials follow in an excerpt which was extracted from an EA letter, SAREA-DE-SO, dated 18 June 1976, Subject: Smoke Test Requirements. Table I presents a brief EA description of smoke materials and effectiveness in screening EO systems. Table II is from the same source and reproduces a list of parameters--generated by the Ballistics Research Laboratory--to be measured in a standardized smoke test. Comments by EA are included to provide a combined list of basic parameters to be measured. Regarding particle-size distribution and density (item 8 in the list), only DPG has the basic instrumentation and calibration procedure to produce these data in the field.

Attached (inclosure 1) is a preliminary report which lists in Table I the various smoke screening materials known to be available to U.S. and Soviet forces. Although there are 12 smoke-producing agents on the list, these can be grouped into general classes with similar screening properties. It is proposed that one agent from each category be included in the test program as follows:

a. Oil smoke: Diesel oil smoke should be selected as the representative oil smoke. The Soviets are known to use vehicle exhaust smoke generators in large quantities and the U.S. is planning to incorporate this capability in the M60-series tanks. Diesel oil and fog oil have almost identical extinction characteristics and, since diesel oil is more representative of what can be expected on the battlefield, it should be the agent of choice in this category. Nothing is known at this time about the Soviet "black" oil formulations. Should intelligence data become available on this smoke it should be included in subsequent tests.

b. Reactive liquids: Titanium tetrachoride (FM) should be selected as the representative smoke in this category. FM is less corrosive than FS and should result in less stringent safety requirements. It is a federal stock item (FSN 1365-277-3028). It is recommended that a vehicle-mounted spray system, similar to that recently observed on Soviet armored vehicles, be designed and built for test purposes.

c. Phosphorus smokes: The principle delivery method for WP is artillery in both the U.S. and Soviet inventories. This could be in a standard WP formulation or a controlled burning form such as PWP or the new wick concept. It is recommended that either the Navy 5-in. Rocket (the MK4, PWP warhead) the XM259 (2.75-in. WP wick warhead) be included in testing. This will represent the best material for screening by minimizing the thermal pluming experienced with conventional WP munitions.

d. Pyrotechnic compositions:

(1) White smoke compositions: Preliminary chamber experiments have shown the Soviet Yershov formulation (DM-11) to have extinction properties very similar to the U.S. HC formulation. Since HC mixes are much easier to obtain and do not contain anthracene, it is recommended they be selected as representative of this category. Available munitions which can be employed include M-8 grenades (FSN 1330-219-8511), M-5 Smoke Pot (FSN 1365-598-5207) and 155-mm Projectile M116 (FSN 1320-383-3890).

(2) <u>Black smoke compositions</u>: There are a number of black smoke compositions in the Soviet inventory and one U.S. black smoke is also available. The U.S. formulation is used in the Navy MK24 submarine marker. It is identical in composition to the mix recently identified in an Egyptian rocket and facilities exists at the Naval Weapons Support Center, Crane, IN, to produce this mix. It is recommended that the MK24 mix be selected as the representative black smoke composition."

TABLE I. EO CHARACTERISTICS OF SMOKES, PREPARED BY EDGEWOOD ARSENAL

	Visible	1.06 μm	3-5 μm	8-12 μm
Diesel oil	Excellent[a]	Fair[b]	Very poor[c]	Very poor[c]
Fog oil	Excellent[a]	Fair[b]	Very poor[c]	Very poor[c]
Oil/by-products mix	Unknown at this time--trying to determine formulation to test			
FS	Excellent[a]	Excellent[a]	Fair[b]	Fair[b]
$TiCl_4$	Excellent[a]	Excellent[a]	Fair[b]	Fair[b]
WP	Excellent[a]	Fair[b]	Poor[d]	Fair[b]
RP	Excellent[a]	Fair[b]	Poor[d]	Fair[b]
PWP	Excellent[a]	Fair[b]		
Poor May have bonus	"hot cloud" effect			
Yershov Mix	Mix being prepared for test in 4Q-FY76			
HC	Excellent[a]	Fair[b]	Poor[d]	Poor[d]
Soviet $KClO_3$ black mix	Mixes are being prepared for test in 4Q-FY76			
U.S. MK24 mix	Mixes are being prepared for test in 4Q-FY76			

[a]*Excellent - Known sensor systems operating in this region can easily be defeated with the given smoke.*

[b]*Fair - Known sensor systems operating in the region can be defeated but a heavy logistics penalty will have to be paid to produce sufficient smoke to sustain the obscuration.*

[c]*Very poor - Smoke is almost transparent in this region.*

[d]*Poor - Sensors could be defeated with this smoke but tactical employment of sufficient quantity is highly unlikely.*

TABLE II. STANDARD MEASUREMENTS IN SMOKE TESTS, ORIGINALLY PREPARED BY BALLISTICS RESEARCH LABORATORY, ABERDEEN PROVING GROUND

Standard measurements for smoke testing	Edgewood Arsenal comments
1. Wind speed	1. Concur
2. Wind direction	2. Concur
3. Sky condition	3. Concur
4. Sun angle	4. Concur
5. Temperature, barometric pressure, relative humidity	5. Temperature gradient as measured at 2- and 6-m heights should be included
6. Visual range	6 Concur
7. C_N - Refractive index structure coefficient	7. Edgewood Arsenal (EA), through Army Research Office, has contracted University of Missouri to measure complex index of refraction of common smoke materials. This value need not be measured in the field since a catalog of values will be available upon completion of University of Missouri effort.
8. Particle size, particle-size distribution, density	8. Particle-size distribution is a difficult and expensive field measurement. Various munition devices to be tested can be characterized and values measured can be used as typical for given device in all subsequent field trials.
9. Transmittance measurements: narrow and/or broad band (a) Visible (b) Near infrared (c) Far infrared (d) Millimeter wave	9. Recommend the following transmittance be measured as representative of current regions of interest. (a) Photopic response (visible) (b) 0.7 to 1.2 μm (region of active IR) (c) 1.06 μm (d) 3 to 5 μm (e) 8 to 12 μm (f) 10.6 μm
10. Record of image taken through various thermal imaging devices	10. Concur. A very useful presentation would be split screen image of visual and thermal image simultaneously.

Table III shows calculated transmission values based on EA extinction coefficient data. Fractional transmissions and attenuations in decibels are given for 10- and 100-m paths in dense smoke (concentration 0.1 g/m) for the four smokes at four wavelengths. Table IV, Developmental Smoke Systems, lists new munitions that can be expected soon, with one exception. The XM761 has a stability problem at high temperature because white phosphorous melts at 110 F. This problem has not been resolved to date. The use of wicks in this round represents an attempt to overcome the traditional thermal pluming problem of WP. The use of PWP or RP is also a technique for overcoming or avoiding this problem.

TABLE III. ATTENTUATION IN SMOKE ENVIRONMENT

Type of smoke	Wavelength (μm)	Extinction coefficient,[a] α (m^2/g)	10-m path,[a] CL = 1		100-m path,[a] CL = 10	
			Transmission	Attenuation (dB)	Transmission	Attenuation (dB)
WP (white phosphorus) or RP (red phosphorus)	0.63	3.32	0.036	14.4	4.0 × '0^{-15}	144.0
	1.06	0.99	0.37	4.3	5.0×10^{-5}	43.0
	4.0	0.35	0.70	1.5	0.03	15.0
	10.0	0.40	0.67	1.7	0.018	17.0
FS (chlorosulfonic acid)	0.63	3.76	0.023	15.9	4.5×10^{-17}	159.0
	1.06	1.38	0.25	6.0	1.0×10^{-6}	60.0
	4.0	0.25	0.78	1.1	0.082	11.0
	10.0	0.25	0.78	1.1	0.082	11.0
HC (hexachloroethan)	0.63	3.87	0.020	16.8	1.0×10^{-17}	168.0
	1.06	1.29	0.28	5.6	3.0×10^{-6}	56.0
	4.0	0.50	0.61	2.2	7.0×10^{-3}	22.0
	10.0	0.10	0.90	0.4	0.37	4.0
Fog oil	0.63	3.73	0.024	16.2	6×10^{-17}	162.0
	1.06	—	—	—	—	—
	4.0	0.20	0.82	0.87	0.14	8.7
	10.0	0.03	0.97	0.13	0.74	1.3

[a] *Extinction coefficient data supplied by Edgewood Arsenal. Concentration, C, is assumed to be 0.1 g/m^3 in all cases. Transmission is defined as*

$$t = e^{-\alpha CL}$$

where α is the extinction coefficient and L is the path length. Attenuation is

$$dB = 10 \log \frac{1}{t} = 4.343\ \alpha CL.$$

TABLE IV. SMOKE SYSTEMS IN DEVELOPMENT, PREPARED BY EDGEWOOD ARSENAL

A. RAPID SMOKE SYSTEM, M60A1/A3 TANK, M239 LAUNCHER, AND UK-L8A1 GRENADE

The M239 Smoke Grenade Launcher with UK-L8A1 RP Smoke Grenade was type classified 5 March 1976. IOC for M60A1A3 Tank was expected in February 1977. Launcher consists of two six-tube grenade dischargers with canvas covers, two six-grenade storage bins, and a push-button firing unit. RP grenade is filled with 0.25-in. cubic pellets consisting of 95-percent red phosporus and 5-percent butyl rubber. Grenade launch creates a smoke screen 30 m from the tank (60 m wide and 8-10 m high) in 2.5 s. Depending on meteorological conditions, smoke screen can persist from 1 to 3 min. This program was recently expanded by DA to the M60, M60A2, M48A5, and XM1 Tank Fleets, MICV and improved Tow Vehicles. Probable requirements have also been established for numerous infantry and Combat Engineering tracked vehicles.

B. VEHICLE ENGINE EXHAUST SMOKE-GENERATING SYSTEM FOR M60A1/A3 AND MULTI-VEHICLE APPLICATION

The Vehicle Engine Exhaust Smoke-Generating System uses existing engine fuel pump to meter diesel fuel from vehicle fuel tanks, through solenoid valves and nozzles, to hot engine exhaust manifolds, where fuel vaporizes. Vapor exits with normal engine exhaust products into open atmosphere and condenses behind vehicle into dense smoke screen. System is driver-actuated and can be operated continuously or intermittently.

Program planning for armored vehicle protection envisions use of an engine exhaust smoke generator to complement other rapid smoke system capabilities and development of single system adaptable to all diesel-fueled armored vehicles. Advanced development was initiated in January 1976. IOC for M60A1/A3 Tank has yet to be established.

C. WARHEAD, 2.75-IN. ROCKET, SMOKE: SCREENING, WP, XM259

The 2.75-in. screening smoke rocket consists of a Mark 40 Mod 3 rocket motor, an XM255 flechette warhead, an expelling charge, a pusher plate, an internal canister containing 10 submunitions (wicks impregnated with WP), a pyrotechnic delay and a WDU-4A/A mechanical fuze. The wick and its configuration control WP oxidation rate and therefore smoke forming rate. A salvo of 19 warheads fired from M200A1 Launcher will provide smoke screen for approximately 5 min over 100- by 300-m area. Type classification is scheduled for FY79 and IOC is scheduled for FY81.

D. 155-m PROJECTILE, SCREENING SMOKE, WP, XM761

The XM761 employs the M483A1 projectile filled with improved white phosphorus payload to produce large persistent smoke screen. Projectile contains 48 cotton wicks saturated with 15 lb white phosphorus. Canister is ruptured and WP wick payload is released when canister is base ejected 30 to 50 m above target. WP wick payload dispersion forms ground pattern of approximately 75 by 150 m. Dispersion pattern and WP wick properties rapidly produce a smoke screen of improved persistence (greater than 5 min) and area coverage. Alternate design is being explored which uses RP wedges in place of WP wicks to control burning rates of munition. Type classification is scheduled for FY78 and IOC is scheduled for FY80.

Table V is a list of older smoke tests prepared by EA. An addition is a test conducted by Army Material Systems Analysis Agency (AMSAA) at Fort Hood, TX during March 1976, where HC and WP artillery and rocket rounds were used in a test similar to the Fort Sill test center.

TABLE V. PARTIAL LIST OF PREVIOUS SMOKE TESTS, PREPARED BY EDGEWOOD ARSENAL SMOKE/AEROSOL TESTS AGAINST IR DEVICES

Proponent	Location	Dates	Comments
MERDC,[a] NAD[b] Crane, NVL,[c] Frankford Arsenal	Crane, IN	Aug 1974	Standard smokes (HC, WP, RP colored signaling) and experimental aerosols were used in realistic quantities against visual and FLIR (3-5 and 8-12 μm) sensors.
NAD [b] Crane	Crane, IN and Avon Park, FL	Feb 1975 Nov 1975	Plasticized WP in 5-in. Navy rockets used against FLIR.
NWC[d]	China Lake, CA	Nov 1975	Variety of standard smokes were used against contractor-owned 8-12 μm thermal imagers and 1.06-μm laser designator systems.
Joint Services EO Guided Weapons CM Group	White Sands, NM	Continuing	Results not available.
MICOM[e]	Redstone Arsenal, AL	Sep 1975	Used single M8 (HC) and L8 (RP) grenades against a variety of developmental EO systems.
AMSAA[f]	Fort Sill, OK	Dec 1975	HC and WP artillery and mortar rounds used against a variety of sensors.
NVL[c]	Camp A. P. Hill, VA	May 1975	HC smoke for M8 grenades used against AN/TAS-3 and -5.
MICOM[e]	Redstone Arsenal, AL	FY72	Effects of tactical aerosols on laser beam propagation using HC, colored smoke, dust, and anthracene smokes.

[a] *MERDC: Army Mobility Equipment Research and Development Center*
[b] *NAD: Naval Ammunition Depot*
[c] *NVL: Night Vision Laboratory*
[d] *NWC: Naval Weapons Center*
[e] *MICOM: Army Missile Command*
[f] *AMSAA: Army Material Systems Analysis Activity*

Table VI lists the tests proposed for 1976 or later. The first and second items have been completed. No report has been received on the third item. No schedule is known for the last item. One important upcoming test not shown in Table VI was recently organized by the Smoke PM Office and AMSAA. An addition to the DT-II test of the Tow night sight will employ various types of smokes at White Sands Missile Range in March 1977. Support for this test will be provided by OMEW, OTD, the Atmospheric Sciences Laboratory (ASL), and DPG.

TABLE VI. INFORMATION ON SMOKE TESTS, PREPARED BY EDGEWOOD ARSENAL

Command/Activity	On-going tests by type	Planned/scheduled testing	Future test requirements	Resource status
MICOM[a] (Re: Msg, DRSMI-RF, 212040Z Jun 1976)	Laser guidance degradation test at RSA (19-23 Jul 1976); visible and IR viewing devices, film, radio, tape, and 1.06 laser transmission. Smoke to be used: L8A1, PWP (4.2), HC, MERDC[b] projected smoke system with RP.	VIPER plans to conduct DT II with some smoke involved; test plan available (DRCPM-VI).	Other field tests being delayed until Office of PM-Smoke is in operation for coordination.	—
EWL/OMEW[c] (Re: Msg, DRSEL-WLM-SL 212058Z Jun 1976)	To support missile system vulnerability analysis, tests of same EO missile system components (TOW and HELLFIRE) and CM devices in smoke environments will be conducted at DPG (22-30 Jul 1976).	Additional vulnerability testing planned, but no definite schedule established. Near-term test requirements can be met by participating in joint field tests which emphasize comparison of missile/night vision devices using current smokes and smokes in development. Data required which characterize smokes in forms which can be used in EWL/OMEW CM/CCM simulator. Measurements are required from 0 3-14 μm.	(1) Test to determine vulnerability of missile systems to use of smoke in operational environment. (2) Tests to determine effects of smoke on CM devices that could threaten U.S. systems. (3) Tests to determine effects of smoke on implemented CCM that could improve survivability of U.S. missile.	Resources include mobile IR facility with capability of making measurements in 3-5 and 7-10 um range as well as weapon system hardware.
PM-AAH[d] (re: Msg, DRCPM-AAH-TM-S, 141933Z Jun 1976) AVSCOM[e] (Re: Ltr, DRSAV-EVN, 18 Jun 1976, subj: Test Information	To determine if there is a requirement to include a direct view optical sight in the target acquisition designation system (TADS) for both the AAH and ASH aircraft, tests have been conducted at Ft. Hood, TX, by OTEA[f] (25-27 Jun 1976). Test included a phase wherein CM were used to evaluate their effect on the test hardware. One of the CM evaluated was smoke.	Planned tests and critical issues to be answered are documented in detail in DA Special Task Force Final Report for AAH/HELLFIRE/ASH Test Integrations. Included are considerations for CM/CCM and for interfaces with other related battlefield systems.	Unaided eye, direct view optical systems and AN-PVS/5 Night Vision Goggles should be included in tests to determine smoke environment susceptability	

TABLE VI. INFORMATION ON SMOKE TESTS, PREPARED BY EDGEWOOD ARSENAL (Cont'd)

Command/Activity	On-going tests by type	Planned/scheduled testing	Future test requirements	Resource status
ECOM[e] (Re: Ltr, DRSEL-CT-L, 23 Jun 1976, subj: Evaluation of Electro-Optical Equipment in a Smoke Environment)	—	—	The Handheld Laser Range Finder AN/GUS-5 and Target Designator AN/PAQ-1 as well as new lasers (2nd-generation lasers) should be tested. Of particular significance are the DF Laser emitting at 3.8 μm and the CO_2 Laser emitting at 10 μm.	Appropriate hardware will be made available for evaluation depending upon scheduled test dates and length of test time.

[a]MICOM: *Army Missile Command*
[b]MERDC: *Army Mobility Equipment Research and Development Command*
[c]EWL/OMEW: *Electronic Warfare Laboratory/Office of Missile Electronic Warfare*
[d]PM-AAH: *Project Manager--Advanced Attack Helicopter*
[e]AVSCOM: *Army Aviation Systems Command*
[f]OTEA: *Operational Test and Evaluation Agency*

Sands Missile Range in March 1977. Support for this test will be provided by OMEW, OTD, the Atmospheric Sciences Laboratory (ASL), and DPG.

3.2.5 Night Vision Laboratory (NVL)

The Night Vision Laboratory (NVL) is primarily a developer of night sights and is concerned with performance of these devices in degraded atmospheres. Closely related is the effort at Frankford Arsenal (FA) in the development of day sights and fire-control systems. Another related effort at Picatinny Arsenal (PA) is in the development of illumination rounds, as one night vision option is the use of day sights with illumination. PA is concerned with modeling of illumination both in clear and in degraded atmospheres.

NVL is currently involved in producing and fielding the series of common module thermal viewers which include the AN/TAS-4, -5, -6, and -4A. In initial production these devices will cost about $14,000 each. Man-portable models use a rechargeable high-pressure N_2 bottle to provide cooling for the detector array (2 hr operation) for operation in the 8- to 12-μm wavelength band. Developmental models of these viewers and of the AN/TAS-3 thermal viewer operating in the 3- to 5-μm band have been made available for several recent smoke tests.

Such tests have established the gross features of the smoke performance of the thermal viewers. In addition, burning material or even hot gasses in the field of view can degrade viewer performance. The appropriate transmission values and the corresponding signal strength conditions required for adequate viewer performance have not been firmly established. Future tests must be designed to provide rather detailed data permitting modeling of viewer performance.

NVL has an excellent capability in visual perception modeling for natural atmospheric conditions. Inputs to the model include illumination, target size and contrast, visual range, and optical parameters of the sight. Outputs are detection, recognition, and identification ranges. It is planned to expand the visual perception model to include the effects of smoke.

A meteorological range is being set up at Camp A.P. Hill, VA. The first year's program addresses such problems as the relation of photo-optic and infrared transmission to visibility estimates, the relationship of measured transmission to aerosol microstructure, and variations in summer and winter conditions. No smoke testing is planned. The problem of major concern in the meteorology community is prediction of target acquisition ranges given current standard data.

It is generally recognized that the standard data (temperature, humidity, visual range, etc.) are inadequate for this objective. The community is looking hopefully to LIDAR as a way of remotely sampling the atmosphere for the necessary additional input to its models.

A tri-service effort will address meteorological problems with the NVL facility, a Navy facility at San Nicolas Island, and Air Force facilities at Wright-Patterson AFB. These problems have taken on increased importance with the proliferation of EO and laser devices and weapons. The visual ranges of interest to the three services have relatively little overlap. The Air Force must have visual ranges greater than 5 to 8 km to operate the equipment of greatest interest. The Navy is most concerned about atmospheres with visual ranges of 1 to 10 km. The Army is most concerned about atmospheres with visual ranges of less than 2 km.

A definition of visual range is appropriate at this point. Visual range, visibility, or meteorological range represents the range for which the transmission of "visible" light is 2 percent. It is also the marginal range at which a high-contrast target is just perceptible (or imperceptible) to an observer who knows where to look. The definition applies for uniform fog in daylight, with the target well resolved. Typical high-contrast targets used in tests include black block letters on a white background or sometimes a naked light bulb. The acquisition range for a low-contrast, surprise target is much less than the visual range. Values as low as 1/4 to 1/2 the visual range are appropriate for recognition of such targets.

3.2.6 U.S. Army Missile Command (MICOM)

MICOM is a developer of weapons, and the smoke work done there supports Project Managers. MICOM has a stated policy not to become a major smoke tester. Recently, however, a large-scale smoke test was conducted which is described later in this section.

Resources at MICOM include extensive testing and range instrumentation. The Propulsion Directorate has a smoke test chamber which is used to characterize rocket exhaust smoke. The chamber is about 6 by 12 ft (1.8 × 3.6 m), of average room height, and has heavy steel walls providing explosion proofing. It has full environmental control and capability for transmission measurements in the visible and several IR bands. There are plans to establish a capability in the far IR and to do particle sampling. The Propulsion Directorate is developing (under contract to Lockheed Corporation) a missile plume smoke model.

The Advanced System Concepts office has a modeling program to describe system performance in a smoke environment. The smoke model is a modified version of the "JTCG model" (so named because of the connection of the Joint Technical Coordinating Group for Munitions Effectiveness to the model's development some time ago). MICOM is presently adding an active and passive IR multiple-scattering formulation to the model.

The activities of several Project Managers at MICOM also are noteworthy. The efforts of the Copperhead (CLGP) PM have already been described. In addition, the Chaparral PM is developing (under contract at Calspan Corporation) a model to evaluate effects of smoke on the Chaparral missile. Calspan is also a prime support contractor for OTD.

The recent MICOM smoke test was conducted by the Laser Measurements Group and ran for three days: 21, 22, and 23 July 1976. The tests took place on Test Area #1, Redstone Arsenal.

Two test scenarios were used to represent typical tactical smoke deployment; one was a "mid-range screen" and the other was a "self-screen." The mid-range screens were produced on the first day of testing and the self-screen smokes on the second. The third day was allotted for some make-up tests and experimental smoke. AMSAA prescribed the configurations and amounts of munitions to provide the desired results. There was no smoke-sampling instrumentation present but transmission measurements were taken at several wavelengths. MICOM basically depended on AMSAA's expertise and experience with smoke to provide the procedures for obtaining the desired concentrations in the field.

The mid-range screens were laid out in a line and detonated remotely. The smoke screen was midway between the observer and the target (a tank). HC, WP, and Plasticised White Phosphorus (PWP) smokes were used for these tests. The self-screens were at a relatively short distance in front of the target (a tank), which itself initiated the smoke. In both scenarios the range between the target and the observers stayed constant at 6000 ft (1829 m). The smokes used in the self-screen scenario were a United Kingdom system (RP), diesel oil fog (smoke), and "Instant Smoke." The last was developed by Mobility Equipment Research and Development Command (MERADCOM) under contract with Atlantic Research Corporation and is discussed in section 3.2.7.

Many EO systems were represented and were operated by the Test and Evaluation Directorate of MICOM. Aeronutronic Ford and Northrup Corporation were present with their versions of beam-rider systems. NVL provided two transmissometers; one for the 8- to 15-μm range and one in the visible (red). The preamplifiers of the various

seeker systems were monitored, and the signals were recorded on magnetic tape along with a time code. The AN/TAS-3 and 4 systems were monitored with videocameras and subsequently recorded on video tapes. The meteorological data as well as the transmission measurement data were recorded with time code information.

The goal with the EO systems were to determine if the systems lost track of their respective targets or sources during the smoke screen and for how long. The various tests were intended to represent the smoke presently found in inventory and smokes expected for future use.

HC was used in the mid-range screen, and as it was used there were some patchy spots. WP and PWP in all applications tended to give good coverage and a thick screen. There was some tendency to plume due to the high heat. As it was used the Instant Smoke was very fast developing, but it billowed upward and did not spread. The oil smoke ("Teledyne system") was slow in producing the screen compared to the phosphorus smokes, but it did not tend to plume. To the eye it appeared to be an effective screen. Full details of the test and test results will be presented in a future MICOM report.

3.2.7 Mobility Equipment Research and Development Command (MERADCOM)

The smoke work at MERADCOM started several years ago in an effort to find ways to mask bridge-building operations.

The present effort is tied to hardware which has been brought through the initial stages of development. The device is a modular-concept smoke grenade which is quite similar to the vehicle-mounted and -ejected British smoke system for vehicle protection, which the U.S. is currently purchasing. There is no in-house smoke work going on, but there is a $150,000 contract with Atlantic Research Corporation (from 23 December 1975 to 23 December 1976) entitled "Instant Smoke as a CM to Smart Weapons." The contract calls for production of prototype hardware, based largely on the design developed previously by the contractor. Prototype units were supplied for the MICOM smoke test during July 1976.

The specifics of the MERADCOM device are as follows. The basic module is a cylinder about 4 in. long and 1.5 in. in diameter (102 by 38 mm). The primary smoke agent is RP. A screw-on assembly makes this cylinder into a hand grenade. Two modules can be screwed into the arms of a "tee" section to form the vehicle munition, the leg of the tee being inserted into an ejector device mounted on the vehicle. This munition also fits the British ejector. When a smoke screen is desired, some of these munitions are ejected to a range of

about 100 m. The canisters begin smoking in flight and the screen is implaced in 0.25 s. The RP smoke is followed by a pyrotechnic smoke of approximately 60-s duration and generated by a solid, slow-burning wafer within the canister.

3.2.8 U.S. Army Material Systems Analysis Activity (AMSAA)

An AMSAA mission is providing systems analysis for DARCOM. In this role AMSAA is the most concerned agency in the generation and verification of smoke models and has recently organized a smoke/aerosol task force. However, AMSAA has long been concerned with smoke effectiveness and will soon be issuing a report on the status of smoke models; thus, coverage in this report is brief.

Two recent live-firing smoke tests were initiated by AMSAA mainly for model verification. These were at Fort Sill in late 1975 and at Fort Hood in early 1976. These tests were supported by the Ballistics Research Laboratories, who supplied and operated a variety of transmissometers and sighting devices during the tests. AMSAA also participated in the recent MICOM smoke test by recommending the deployment of smoke munitions to produce the desired smoke screens.

One of the most comprehensive smoke models has been put together by AMSAA and is generally referred to as the "Smoke Obscuration Model." This model is also a modified version of the JTCG model and consists of three major parts: the mechanical model, the optical model, and the perception model. In the mechanical model the diffusional growth of the smoke cloud is described as a time and spatial distribution of aerosol concentration. Inputs are number, type, and location of munitions and meteorological conditions.

In the optical model the apparent relative contrast of target and background at the observer's position as affected by the smoke cloud is determined. Inputs are target and background characteristics, atmospheric conditions, and illumination conditions. For the last, the Sky Partitioning Program is used to model the illumination of the target, background, and smoke cloud. A Mie scattering program is used to model scattering properties of the smoke cloud. A special generating program provides a typical aerosol particle-size distribution based on measured smoke properties and on the input meteorological conditions. The output of the optical model can be transmission along a particular line of sight as a function of time, or the output can be the extent of the obscured region, that is, all those lines of sight for which transmission is below a minimum value (5 percent is usually used). In the perception model the relative contrast and brightness at the observer's position are compared to threshold levels, and a probability of detection is calculated.

3.2.9 Ballistics Research Laboratory (BRL)

BRL has served as a support agency providing instrumentation for smoke tests. In this capacity BRL has participated in the AMSAA smoke tests. They supported a test of 2.75-in. wick WP smoke rockets fired from hovering helicopters at Fort Hood in March 1976, and in May 1976 BRL and AMSAA were involved in the testing of L8A1 grenades which were launched from the M1CV and M113 vehicles. At these tests the BRL measurements included broadband transmittance (0.4 to 0.7 μm, 0.7 to 1.1 μm, 3 to 5 μm, 8 to 14 μm), visual contrast, and visual range. Thermal imaging devices also were supplied by BRL at these tests. In early June 1976 BRL was involved in a smoke test utilizing 155-mm WP (static fired), HC smoke pots, and fog oil smoke pots. In addition to the above measurements, 95- and 140-GHz radiometers were employed at this test.

3.2.10 Atmospheric Sciences Laboratory (ASL)

The ASL provides meteorological support for tests at White Sands Missile Range (WSMR) and for other Army activities and conducts widespread research in meteorology. For example, ASL supported NVL in the recent Grafenworh measurement program. In that effort extensive use was made of the Knollenberg counter in measurement of aerosol particle-size distribution and densities.

Much of ASL's work is concerned with long-range (many-kilometer) propagation effects in a clear atmosphere. For example, they have developed a differential spectrophone technique[3] for measurement of absorption by atmospheric dust.

In the area of battle field smoke, ASL has several on-going research programs which are quite relevant. These programs include an effort at field characterization of smoke in support of DPG and OMEW, and a rather large effort to develop a laboratory capability for measuring relevant optical constants of naturally occurring particulates and solid aerosol smoke materials. A small project (a half-man-year effort) of interest deals with the measurement of size distribution, composition, and imaginary index of dust raised by military vehicles at WSMR. This effort represents the only known work on the incidental smoke and dust problem.

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[3] *S. A. Schleusener, J. D. Lindberg, K. O. White, and R. L. Johnson, Spectrophone Measurements of IR Energy Absorption by Atmospheric Dust, Applied Optics, 15, No. 10 (October 1976).*

3.2.11 Atmospherics Community

One branch of the atmospherics community is the meteorological community, which includes NVL, ASL, the Institute for Defense Analysis (IDA), the Air Force Geophysical Laboratory, and other Air Force and Navy elements. Some of the efforts by this branch were described under the NVL and ASL sections.

Another branch of the atmospherics community, quite independent of the meteorological branch, is composed of the optical fuzing groups with interest in air-target or ground-approach proximity fuzing. Included are HDL, the Naval Weapons Center (NWC), and various industry and university groups.

The resources of these groups most relevant to smoke include instrumentation and expertise for characterizing natural aerosols (clouds and ground fog), computer models for Mie scattering and the detailed analysis of backscattered signals and aerosol discrimination techniques, and extensive data from cloud and target measurements. Of particular interest may be a scattering model at NWC, which includes multiple scattering effects, and a two-channel nephelometer at HDL which has been employed in cloud-mapping work and which will be discussed further in section 3.4.

3.2.12 Groups and Committees

In addition to the agencies mentioned there are several tri-service organizations with interest either in the characterization of smoke or with EO system smoke performance. These are listed below.

(a) Smoke/Aerosol Working Group (SAWG) of the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME)

(b) EO Sensor-Atmospherics Working Group

(c) Optical/Submillimeter Propagation Working Group

(d) Ad Hoc Working Group on EO CM--Army Science Advisory Panel

(e) Working Party for Laser Ordnance Applications (WPLOA) of the Joint Technical Coordination Group for Munitions Development (JTCG/MD)

The SAWG is composed of interested individuals from various agencies of the three services. Their scope of interest, within the group, is primarily degraded atmospheres with heavy emphasis on the

determination of "combat effectiveness." The SAWG holds quarterly meetings at which information is exchanged and specific questions are taken up for discussion at working sessions. Planned activities for the future include the publication of a "smoke education" pamphlet for field-level uses and continuing effort on the production of a Joint Munitions Effectiveness Manual on smoke.

Groups (b) and (c) have essentially common membership: representatives of the military meteorology community. They are concerned primarily with meteorological problems and target acquisition, subjects closely related to EO weapon performance in smoke.

The EO Sensor Group was formed under the Joint Logistics Commander's Tri-Service Panel on Night Vision (NV) Technology and is chartered to coordinate atmospheric program strategy and application requirements for the tri-service EO sensor community.

The Optical/Submillimeter Group was formed by DDR&E to assess present technology and propose recommendations in the area of environmental effects on propagation in the optical and submillimeter wavelength regions.

The Ad Hoc Working Group on EO Countermeasures is drawn from representatives of industry and universities. The group reviews Army research and development in its area of interest and reports to Army Scientific Advisory Panel (ASAP) which in turn reports to the Army Chief Scientist.

The last group, (e), is again a tri-service panel under the Joint Chief, Logistics, consisting of interested individuals from the three services. Several subgroups concern special interests in lasers, CM's standards, laser safety, etc. The group has encouraged adoption of common standards which will permit interoperability of laser-guided weapons.

3.2.13 Operational Agencies

As stated previously, this section only lists some operational facilities and indicates the nature of their operation.

The Operational Test and Evaluation Agency (OTEA) is a field-operational facility of the Army General Staff. It is concerned with operational testing of equipment and is independent of DARCOM and TRADOC. OTEA has not been active in smoke tessmoke in the future.

TRADOC agencies that are concerned with smoke testing include CACDA, TRADOC Combined Arms Test Activity (TCATA), Combat Development Experiment Center (CDEC), and TRASANA. The group at CACDA has been mentioned and, although currently small, is the central directional authority for smoke testing in TRADOC and therefore is the counterpart to the PM Smoke in DARCOM. CACDA's combat operation analysis group does work in smoke modeling.

TACTA (formally MASSTER) at Fort Hood and CDEC at Hunter-Ligget are facilities where operational smoke tests can be carried out in the field. TRASANA is the analysis agency for TRADOC and is deeply involved in force-on-force and smoke modeling.

3.3 The Correspondence of Existing Resources and Technology to Testing Needs

The scope of EO system smoke testing and of the test structure was described in section 2 and illustrated by figures 1 through 4. It is apparent from the review of the resources that, in a number of areas, the requirements within the testing scope can be met. In this section several areas of correspondence between resources and needs are noted, with some discussion of weaknesses and specific technical problems.

In figure 2 the requirements for the structure's field test capability were outlined. This is the area where munitions and operations are tested in as near to real-world battlefield conditions as can be simulated on the firing range. In this area, the major categories of large-scale tests, characterization of the environment, and system performance are indicated in figure 2.

Large-scale tests or force-on-force exercises involving troops and equipment must be conducted by the operational community where organizations such as CDEC or TCATA have facilities and are equipped to conduct such tests. Instrumentation to characterize the environment in these exercises can be supplied by DPG and other members of the technical side of the structure, if desired. It appears that a substantial effort will be required to develop the techniques to monitor and analyze human behavior in these tests.

The characterization of U.S. and foreign smoke munitions under battlefield conditions requires range facilities and instrumentation grids such as those that are being developed at DPG. The TECOM recommendation that DPG be the center for this type of effort is endorsed here. Other possible locations where instrumented range facilities could be set up for limited tests include several of TECOM's proving grounds and MICOM. At some of these locations smoke deployment must be accomplished by static means to relieve range and

safety requirements but at the expense of realism. Existing field characterization technology is well developed but some advances are needed. This point is discussed in detail in section 3.4.

Meteorological support and EO device and instrumentation support in past smoke tests have been provided by ASL, NVL, OMEW, BRL, or supporting groups within MICOM. These organizations will undoubtedly be available to perform in similar roles in future smoke test programs.

One environment which has been more or less neglected in previous tests and data gathering programs is that of natural aerosols with visual ranges of less than 1 km. Existing technology and resources can fill this gap for many conditions, but some pose special problems. These include flowing fog, low-altitude fragmentary clouds, and ice fogs which, in general, are large-particle, high mass concentration aerosols with properties similar to those of clouds and which block radiation of all wavelengths visible through long-wave IR. Work with ice fogs is additionally complicated by the nonspherical nature of the scattering particles.

Other neglected natural conditions which are somewhat more difficult to characterize than water or even ice fog aerosols are snow, blowing snow, and blowing dust.

For light fog and haze (visual ranges generally greater that 1 km), NVL and ASL have carried out and are planning further measurement programs. Another previously neglected environment of great importance is that of incidental dust and smoke. ASL is beginning some work in this area, but a comprehensive program coordinated within the structure will be required. No major technical problems are expected in this effort, but the difficulty in assessing the relevance of test environments will not be small.

For research or advanced development efforts, test operation of systems in the environment characterized by the above resources will most likely be conducted by the various Project Managers or development agencies. For systems in later development, smoke performance would be included in DT or OT testing programs. It is intended that system developers can call on the PM Smoke for recommendations on needed testing and performance requirements, and he can then direct them through the structure. Smoke Week, if that suggestion is carried out, would provide developers with an opportunity to conduct their own performance tests under field conditions in well-characterized environments.

Figure 3 outlines laboratory testing requirements of the structure. Measurements are needed of characteristics of U.S. and foreign tactical smoke and of research or developmental obscurants in instrumented chambers under controlled conditions. Such work is being done very competently at EA and FA; ASL is apparently also developing some capability in this area.

Natural aerosols again are a relatively neglected area though a good technology base exists in the fuzing branch of the atmospherics community. Incidental smoke and dust are, in general, so poorly defined that laboratory measurement or characterization is only a remote possibility. An exception is the effort on rocket motor work at MICOM. In the context of this report the missile exhaust is incidental smoke.

System tests under simulated conditions will generally be conducted jointly by the developers and structure members. Existing facilities may be adequate but are not overly abundant. Of particular value may be the large chamber at DPG, where systems can be operated in a smoke environment over the full military range of temperature and humidity. The planned chamber at Fort Huachuca may also provide a testing facility of great flexibility.

In figure 4 the modeling requirements of the structure are outlined. Smoke models have been developed by the JTCG/ME and DPG, and are being pursued at several other agencies. A smoke obscuration submodel is being incorporated by AMSAA into its force-on-force model. All this work must be coordinated and appropriately continued to develop some of the structure's needed modeling capability.

NVL and FA have played a strong role in development of the optical and perception models. Additional effort is needed on smoke obscuration models, and the groups already involved are the obvious ones to continue. Extension to force-on-force modeling requires the development of additional methodology, and AMSAA and TRASANA must be involved in such an effort.

Verification of models requires comparison of computed results with field test results. Greater effort is needed in this area, and AMSAA is actively advocating this work. The instrumented range grids and methodology being developed at DPG will contribute greatly to the verification process. Full details on models and their state of validation will be available in AMSAA's forthcoming report.

Overall, the Army's testing resources, as indicated in the above discussion, are generally good and quite broadly based. To meet the Army's smoke testing needs both fully and efficiently, the greatest

requirement is for the proper coordination, guidance, and support of ongoing and future efforts. Fulfilling this requirement is the purpose of outlining the formal test structure in the other sections of this report.

3.4 Aerosol Characterization in Field Tests

Before proceeding with a discussion of field tests, some elementary comments on the technical aspects of the interaction between aerosols and EO systems might be helpful. In most of the optical systems of concern here, a common requirement is the propagation of optical wavelength radiation from a target or beacon (or both) to some type of receiver. The radiation detected from the target may have been originally generated by a laser or another source which is part of the system (as in designator systems or in active optical fuzes), or it may be scattered sunlight (as in visual observation) or other natural radiation (as in starlight viewers), or it might be thermal radiation generated by the target itself (as in thermal viewers). In the case of a beacon, the source of the radiation detected by the receiver is obviously the beacon itself. In a clear atmosphere, the performance of such systems is generally limited only by the quality of the system itself, the characteristics of the target (its IR signature or its reflective properties, etc.), and perhaps the background conditions. When an aerosol is introduced in the propagation path or even in the vicinity of the target or the system, a variety of effects can occur.

Perhaps the most well-known effect is the attenuation of the radiation as it propagates through the aerosol. This attenuation is caused by two distinct mechanisms: absorption and scattering of the radiation by the aerosol particles. The attenuation can generally be described through Bouguer's (or Beer's) Law:

$$I = I_o e^{-\alpha L} \quad , \qquad (1)$$

where I_o and I are the initial and final radiant intensities over the path length L of uniform aerosol. The limits of applicability of this law are determined by the strength of the forward scattered radiation and can be expressed in terms of the aerosol's optical thickness (i.e., αL). These limits are quite broad[4] and, for discussion in this report, the law can be assumed valid.

[4] *V. E. Zueu, M. J. Kobanov, and B. A. Savellev, The Limits of Applicability of the Bouguer Law in Scattering Media for Collimated Light Beams, Izv. Atm. and Oceanic Phys., 3, 7 (1967).*

The quantity α is usually termed the attenuation or extinction coefficient and is expressed in units of inverse length (usually meters^{-1}). Another formulation* of Bouguer's Law is

$$I = I_o e^{-\alpha CL} , \qquad (2)$$

where α is again (unfortunately) commonly termed the extinction coefficient but in this case has units of meters^2 per gram, and C is called the "concentration" and is simply the mass per unit volume (grams per meter^3) of aerosol. The two formulations are equivalent, but equation (2) explicitly indicates the dependence of attenuation upon mass concentration. For either formulation, however, the extinction coefficient is composed of two parts: the first, σ, describes the attenuation due to scattering, and the second, γ, describes that due to absorption. Hence,

$$\alpha = \sigma + \gamma . \qquad (3)$$

In some cases, such as near-IR radiation in petroleum oil smokes or natural aerosols, for example, the attenuation is almost entirely due to scattering; hence, the quantity γ is negligible compared to σ. In other cases, such as far infared in natural aerosols, scattering and absorption are almost equally important. There are also, of course, cases, where absorption is the dominant effect.

The effect of attenuation upon the systems considered here is quite apparent. Signals reaching the receiver are reduced from their clear air levels and may, in fact, fall below some required detection or tracking level. In viewing devices, even if target perception is possible, detection ranges are degraded. In some systems a particularly severe problem can arise if one portion of the system (a sight, for example) remains functional while another (say, a guidance link) is not. In certain active systems the attenuation problem is compounded, since the radiation of interest may be required to traverse the aerosol twice (from the source to the target and from the target to the receiver). These effects can be continuous over some interval of

**The formulation in equation (1) appears to be used by the atmospherics community; that of equation (2) is used throughout the smoke community.*

time or be intermittent as cloud conditions evolve through chemical reactions and changing meteorological conditions. Some systems, because of their logic designs, may be particularly affected by such an intermittent degradation.

Another important effect of smoke on systems is related to that scattered radiation discussed in the context of attenuation. That scattered radiation can reach the receiver and can itself obscure the target or present the system with false targets. For example, a laser terminal homing missile could quite possibly home on the energy scattered from the leading edge of a smoke cloud rather than on the target within or behind that cloud. Another example is active optical fuzing for air target munitions. This technology has always struggled with the problem of mistaking energy backscattered from clouds as energy reflected by targets.

The most striking example, perhaps, is that of visual observation. In that case so much light from the source (sunlight) can be scattered from the aerosol to the receiver (the eye) that the target cannot be detected (i.e., one sees the smoke and not the target in or behind it). In thermal viewing devices, such scattering can create a more intense background or foreground in which the target must be observed. There is also the possibility that for some time during its existence the cloud itself is a hot body which radiates unwanted energy* to the receiver, thereby obscuring the target or creating false targets.

The discussion of the more important interactions of aerosols with systems can now serve as the background for an examination of some special considerations in developmental field testing.

Many complicated problems in field testing depend upon the purpose of the test and are addressed by a variety of techniques familiar to the reader. This discussion does not attempt to cover all of these problems, but focuses on one of the issues of prime importance in any type of field test. That issue is the identification of the

**Though the discussion here is limited to the effects of the cloud itself, there is a problem of very strong thermal radiation from the flash of an exploding smoke munition or from burning material disseminated by the munition (such as wicks or chunks of phosphorus). This radiation can temporarily swamp the receiver or present false targets.*

nature and relevance of the environment in which the test was conducted. Though the importance of this issue may appear obvious, it has received only varying degrees of attention in previous tests.

Note that two distinct aspects of the environment have been stressed here: its nature, which means its physical characteristics; and its relevance, which means its representation of possible battlefield conditions.

The identification of the nature of the test environment is conceptually straightforward. This characterization requires the measurement of those properties of the aerosol which control the interactions described previously. Those properties are specified by a well-developed theory which describes the propagation of electromagnetic radiation in aerosols consisting of spherical particles.[5,6] The theory is founded upon the Mie analysis[7] of scattering by a single spherical particle and leads to a characterization of aerosols in terms of various parameters. All or certain combinations of these parameters must be utilized to analyze test results and thereby make the test meaningful. The simplest examples of these parameters include the extinction coefficient of equation (1) [or (2)] and, pertaining to scattering, a volume scattering coefficient usually designated as $\mu(\theta)$, where θ is the angle between the scattered and incident rays. The values of all the parameters are determined by the radiation wavelength and some basic "optical" properties of the aerosol, namely particle index of refraction, number density of particles, and the size distribution of the particles. In a test one therefore has the choice of measuring the parameters of interest or the more fundamental properties of the aerosol. For either approach, the problem is complicated by the fact that the aerosol properties can vary rapidly in both space and time. Thus, in the ideal case the measurements would be made over the identical paths traversed by the radiation processed by the system under test and simultaneous to the test. Furthermore, these measurements must be made with some degree of both spatial and temporal resolution. The required resolutions are in part determined by the system under test and are discussed further throughout this section.

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[5] *W. E. K. Middleton, Vision through the Atmosphere, University of Toronto Press (1952).*

[6] *H. Van de Hulst, Light Scattering by Small Particles, John Wiley & Sons, New York (1962).*

[7] *G. Mie, Ann. Physik, 30, (1908), 377.*

In most previous field tests of systems in smoke the approach has been to measure, if anything, only the extinction coefficient. This has usually been accomplished by simple transmission measurements through the smoke using optical sources of various wavelengths. In the more recent tests attempts have been made to have the optical paths of these sources coincide with the path of the system under test, but physical limitations usually restricted these attempts to achieving only a common intersection volume within the cloud. The temporal resolution of these measurements is usually quite good, being limited only by the response time of the receiver or recording devices as transmission is recorded continuously. Even in the worst case (where, for example, a chart recorder is used to record data) the response time is on the order of milliseconds, which should be sufficient when one considers cloud growth processes. The spatial resolution of such measurements is, however, rather poor. This occurs because the transmission measurement is usually made over the entire width of the cloud or over some large segment from its leading edge to a receiver or reflector near the target. This measurement provides the loss of optical energy incurred in traversing a large path length (the length is usually determined from marking stakes and photographic records of the cloud) which in turn gives the extinction coefficient through a simple inversion of Bouguer's Law. Such a measurement yields only an average value of extinction coefficient over the path length.

In certain tests such large-scale averaging may be adequate. For example, in testing some passive systems the quantity of primary interest is the energy loss suffered by radiation originating at the target and passing through the smoke. A detailed knowledge of the cloud's structure is not, therefore, needed for an understanding of the system's behavior in the test. In other tests this is not the case. An obvious example is in the testing of a smoke-producing device, where the detailed spatial structure of the cloud is primary information. Another general example is in the testing of active EO systems, where scattered energy is a critical factor in the systems performance. For those systems not only is more information than the extinction coefficient required, but those data may well have to present a much more detailed picture of the propagation paths than simple long-path average values.

An estimate of the required spatial resolution can be obtained from some elementary considerations. In most cases, difficulties in interpreting test data might result from local regions within a cloud which possess characteristics very much different from the large-volume average ones. For natural aerosols, experimental data show significant

changes in properties on a scale of a few meters or less[8,9] (how much less is unclear). For smoke munitions the structure would not be expected to exceed this size, so the ability to resolve measurements to a scale of about 1 m is highly desirable. This value may be too large or too small,* according to the system under test and the purpose of the test. One guideline concerning the estimate is the shortest time interval of interest to the system. This quantity is relevant because the scattered signal received at any instant, from a transmitted signal of duration T, originates from a segment of aerosol cT/2 long, where c is the speed of light. For example, in very short pulse or fast rise-time systems (in the few nanoseconds range), where pulse distortion may be an important feature, the spatial scale of interest is under 1 m. Thus, it is clear that resolution requirements should be considered on an individual test basis. One special case worth noting is that of wide-angle systems, such as fan-beam optical fuzes. For these systems the angular resolution of the environmental measurements also is important. This consideration can result in multiple or scanning narrow-beam probes of the test path. Angular separation of the probes or scan rates would be set by the expected aerosol structure or by the properties of the system under test, or both.

In most field tests in smoke to date, spatial resolution requirements have not been addressed. In most tests only the long-path average extinction coefficient has been measured. An interesting point is that in some tests the data produced by the system under test can itself yield information useful for a description of the aerosol. This point is not surprising in view of the similarity of these systems to (optical) atmospheric probing instruments. Such instruments, which are generally lumped into the category of LIDAR, must be considered for achieving the required quality of aerosol characterization. Many such devices have been used in the past, though primarily in air pollution projects or atmospheric turbulence studies. Several devices have also

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[8] *R. W. Withers, Quantitative Measurement of Aerosol Backscatter Using a Fan-Beam Active Optical Sensor, Motorola Inc., presented at the First Tri-Service Optical Fuze Technology Symposium, sponsored by the Joint Technical Coordinating Group for Munitions Development, Working Party for Fuzes (May 1976).*

[9] *D. Giglio, B. Rod, and H. Smalley, Nephelometer Mapping of Backscatter and Attenuation Coefficients of Clouds, Harry Diamond Laboratories TR-1660 (February 1974).*

**From an academic point of view, no scale is too small, provided it remains at the macroscopic level. From the view of a developer whose system is undergoing testing, a scale is too small when a larger one could have produced sufficient information for the test at a lower cost.*

been used in smoke tests or studies. For example, HDL has for several years employed a special-purpose nephelometer in the study of natural aerosols. This instrument has been used in studies of ground fogs, in flight tests for the study of clouds, and in support of optical fuze tests. In these flight tests the device produces, within certain limitations, a continuous map of extinction coefficient (α) and volume backscatter coefficient ($\mu(\pi)$) along the entire test path, with a spatial resolution of about 7 m. A more well-known example in the smoke community is the Backscattered Laser Energy Digitizing Equipment (BLEDE) developed under contract for OTD. This device is fairly typical of conventional LIDAR's, which generally operate by transmitting a pulse of optical energy into the aerosol and then attempting to discern atmospheric properties by an examination of the backscattered signal. Such devices offer the possibility for remote high-resolution measurements, but there are several limitations on their performance.

Some limitations arise only from the operational concepts that LIDAR developers have employed. Specifically, most conventional devices operate by measuring the discontinuity in the clear-air backscatter signal caused by the smoke cloud. This discontinuity, which simply represents the total energy loss across the cloud, is then used to compute the cloud's extinction coefficient by a manipulation of the scattering equations. Inherent in this analysis is the assumption of a uniform aerosol, and the result is obviously the same type of long-path-average extinction coefficient as obtained by the transmission measurements described previously. This average extinction coefficient is then usually employed to compute some type of average volume backscatter coefficient from the peak signal received from the cloud. This type of LIDAR design is not only limited in its spatial resolution but also has a self-imposed requirement for "penetrating" ability. That is, a measurable signal must be received from the clear air beyond the smoke cloud for the computation of the average extinction coefficient. Thus, the system is required to fully penetrate the cloud for proper operation. The limitation imposed by this requirement can be quite severe, as the transmitted energy which gives rise to the signal from the far side must pass through the entire cloud twice. The limitation is set by the aerosol properties, the operational range, and the system design parameters (e.g., transmitter power, dynamic range, etc.). In the BLEDE system, for example, published specifications[10] and some reasonable assumptions about its characteristics lead to the conclusion that it will penetrate clouds of 0.2 m^{-1} average extinction coefficient at a range of 1 km only if the thickness of those clouds is about 10 m or less.

[10] *C. R. Odom, Measurement of Atmospheric and Smoke/Aerosol Parameters During CM Tests, presented at the Seventh Department of Defense Conference on Laser Technology, West Point (June 1976).*

The problems in conventional LIDAR's are not unresolvable. Several good concepts exist within the smoke community for improving resolution to a high degree. Some concepts extend to the use of multiple receivers or directional reflectors to increase the amount and quality of data provided by a single instrument. Research in this technology, supported and coordinated by the test structure, can lead to workable designs in a relatively short time. A high-measurement capability can be produced if these designs are implemented with state-of-the-art laser and detector technology, digital signal-processing techniques, and modern data-reduction software.

The discussion has so far dealt with the direct measurement of scattering parameters (and therefore by necessity with optical techniques) and not with the measurement of basic optical properties of the smoke cloud. It is conceptually feasible, given enough data and computation time, to derive the optical properties from the scattering parameters[11] through an inversion analysis. This approach was not pursued to any great extent in previous times, but the direct method of particle collection has been employed. Collection technology is extremely difficult and instrumentation development has gone through a long evolution. Historically, the first reliable particle-size distribution measurements of fog were done by a spider-web technique developed by Dessens.[12] The technique required the preparation of a web network, collection of the sample, and microscopic examination of the sample immediately following collection and in the same environment. In his landmark study of natural fog about 1950, Arnulf[13] used the spider-web technique, since even then it was the most reliable for particle-size measurement. At present an array of samplers and counters using various physical principles is available, each with its associated problems. Most of these instruments have been discussed in connection with DPG because of their intense efforts in this area.

It should be apparent that particle measurements are difficult in relatively stable aerosols such as natural fog. Add to that, for smoke, the complexity of the random or erratic performance of smoke munitions, dust, thermal effects, and meteorological effects in a dynamic environment, and perhaps the difficulty of smoke characterization can be appreciated.

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[11] *B. M. Herman, S. R. Browning, and J. A. Reagan, Determination of Aerosol Size Distributions from LIDAR Measurements, Journal of Atmos. Sci., 28, 763 (July 1971).*

[12] *H. Dessens, Les Noyaux de Condensation de L'Atmosphere, La Meteurol, 321327 (1947).*

[13] *A. Arnulf, J. Bricard, and C. Veret, Sur La Propagation des Radiations Visibles et Infraouges a Travers Le Brouillard, Comptes Rendus 230, (1950), 565-567.*

The question therefore arises of whether sampling techniques should be employed in field tests, especially in view of the great potential for measuring scattering parameters by optical means. The answer is affirmative for a variety of reasons.

One basic reason for using sampling techniques in field tests is that LIDAR concepts, even when the previously described capability is achieved, are currently limited to the measurement of extinction and volume scattering coefficients at only a few possible wavelengths. For some current and probably many future systems, additional aerosol characteristics at a variety of wavelengths will be required for their test and evaluation. Direct measurement of these characteristics by optical techniques may prove technically difficult and will certainly result in more complicated and expensive instruments. Alternatively, the measurement of the basic optical properties provides the needed input for the analysis of any system. Furthermore, there are no real alternatives to particle collection techniques for developing a full smoke chamber capability within the structure. Samplers not only will be used to characterize the smoke produced within the chamber, but also must be used in the field for identification of the expected differences between the actual and simulated environments. In addition, collection techniques will be indispensable to the needed work in incidental smoke and dust, where identification of the origin of the particles will be as important as the determination of their optical properties.

Finally, it should be noted that the capability reported by DPG includes the simultaneous production of temporal histories of optical properties from multiple samplers. Though the temporal resolution of these histories may be only on the order of tens of seconds, this capability offers flexibility in terms of spatial resolution requirements, though setup and sample analysis costs are limitations. Thus, one might conclude that for the immediate future our ability to characterize smoked environments by collection techniques is comparable to that by optical techniques. For the near term, therefore, a combination of techniques must be used, with heavy reliance on DPG. In the long term, it is expected that a combination would still be employed. Optical methods will produce accurate, high-resolution measurements at specific wavelengths which, when combined with data from sampling stations, will produce the information needed to understand the performance of the system under test.

The final point to be considered here deals with this question: "Given that the optical path of a system under test is characterized with whatever accuracy and resolution desired, what is the relevance of this path to a battlefield environment?" The answer is that, because of the unlimited variety of possible cloud properties

and propagation paths (even when munition, terrain, and environmental conditions are specified), the path in a single field test has no special significance and only represents one point in a virtual continuum of random possibilities. The approach to be taken, therefore, is to use the field test to provide reference data for a scan of the continuum (through modeling) which would yield a statistical picture of the system's performance in battlefield smoke. Undoubtedly, attempts will ultimately be made to reduce the results of the statistical analysis to simple measures or figures of merit which meaningfully describe the system's technical capability in smoke. A suggested approach for this data condensation is to extend the concept of clear line of sight (CLOS) to smoke. The CLOS,[14] or intervisibility,[15,16] concept is already a familiar one within the Army and has been developed in connection with screening by terrain and vegetation. The extension of this concept to smoke will require the inclusion of a statistical range consideration, as well as the conventional time duration of CLOS.

Unfortunately, the current modeling capability of the structure is not developed enough for the full implementation of this statistical approach. In fact, field tests in the near future should be as fully concerned with obtaining model validation data as with testing systems. Until the methodology and modeling capability for the full statistical analysis is available, the structure must use all available field data to provide the broadest possible picture of a system's performance in smoke. This substitute approach includes the use of smoke munitions in the quantities and patterns tactically appropriate to the test scenario under the most typical expected conditions (of temperature, humidity, wind, etc.) and the probing of the smoke along a variety of paths (in addition to the test path). The test results can then be viewed in terms of what could have occurred along other equally representative paths in a simulation of expected conditions. This extension of results to other paths should include also those observed in other tests, a step tied to the data bank discussed previously. This process amounts to a "manual" attempt at duplicating the analytical power of modeling. The manual approach is limited by the number of conditions which can be simulated (e.g., the

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[14] *W. H. Leonard and J. E. Kirshtein, Tactical Operations Assessment, Attack Helicopter--Daylight Defense Experiment, CDEC Experiment 43.6, Army Missile Command Report No. RB-TR-72-1 (March 1972).*

[15] *T. J. Gleason, M. E. Sword, and R. L. Gorman, Intervisibility Beacon System, Phase II Final Report, Harry Diamond Laboratories PR 74-2 (August 1974).*

[16] *T. J. Gleason and M. E. Sword, Intervisibility Beacon System, Phase I Final Report, Harry Diamond Labortories PR-74-1 (June 1974).*

humidity at DPG or WSMR may never be suitable for a simulation of operations in some parts of Europe at certain times of the year), the infinite variety of paths in each test, and the monumental cost of testing over a range of all possible variables (even if it could be done). The limitations are the reasons for advocating the modeling approach in the first place.

4. SUMMARY AND RECOMMENDATIONS

An approach by which the Army may thoroughly and efficiently deal with the overall problem of smoke testing and effectiveness assessment has been described in this report. This approach will be reiterated here in the form of a list of summary statements and recommendations which deal with specific actions as well as a philosophy to be adopted.

(a) The use of smoke generally impacts all battlefield functions of both sides. The impact is greatly dependent upon many factors and is one of degree; that is, it degrades or enhances systems or actions to varying extents for various segments of some interval.

(b) The overall goal of smoke testing should be to assess the effectiveness of the subject (be it a smoke munition, a weapons system, a tactic, etc.) in smoke on the battlefield.

(c) Effectiveness can be assessed only through a comprehensive testing process which recognizes the importance of developmental and operational considerations and their interrelationship.

(d) The evaluation must generally culminate in computer simulations which weigh the impact of smoke on the test subject and all other battlefield functions of both sides.

(e) The simulation models must be supported by a variety of submodels, which, separately and in combination, must be founded upon and verified by field and laboratory tests in an iterative process.

(f) The modeling capability and the network of test facilities, both developmental and operational, should be organized with leadership teams provided by the PM Office and CACDA into a unified entity in a functional sense. This entity, which must extend across agency and possibly service bounds within the DoD but which will mainly consist of Army facilities, defines the Army Structure for Effectiveness Assessment.

(g) Because of the broad capabilities which the structure requires to assess effectiveness, virtually every member of today's smoke community will become a member of the structure because of one or

more of its programs or capabilities. In many cases, the same members and possibly the same programs will have other roles or applications in the Army's overall effort to develop its desired position with respect to smoke. Thus, members of the structure may also be users of the structure. This situation, along with the leadership's ability to foster communication and influence programs across agency bounds, should provide for maximum utilization of resources and a fully coordinated Army smoke program.

(h) The resources of the structure should be utilized as early as possible in the development cycle of hardware or concepts. The structure should therefore promote an awareness of the smoke threat and its technical and tactical implications. The structure should also promote an awareness of its own capabilities, both to prevent duplication of effort and to inform developers of available services.

(i) The structure leadership should not become involved in any way (unless requested) with a developer's testing in his independent research. If, for example, a developer wishes to test in smoke a new concept or design modification, he should be free to do so with whatever facilities he believes adequate. This facility may be a local one which he maintains, such as a simulation chamber or an analytical smoke model, or that of a member of the structure working in direct support of the developer. The existence of a local facility would not conflict with the structure or be inconsistent with statement (g). This facility would interact closely with the structure on the technical level and in a sense would be part of the structure even though it served only a limited purpose for a single developer.

(j) The leadership organizations should coordinate their activities and reach a mutually agreeable course of action for implementing a testing approach and structure concept similar to that described in this report. The following specific actions are recommended for implementing and operating the structure:

(1) The leadership organizations should seek participation or membership on the appropriate tri-service working groups or panels. By this step, they can influence the activities of these groups and open lines of communication to other services.

(2) The smoke symposium should be held.

(3) The leadership should organize technical reviews of existing resources. Some of this effort may be combined with the smoke symposium activities.

(4) The concept of a smoke week should be evaluated.

(5) The structure leadership should review all previous tests and test results to gain further expertise in testing and also to start the needed data bank.

(6) To meet the needs of those systems which require smoke testing in the immediate future, the leadership should contribute to the test and evaluation plans for those systems and recommend the best plan possible based on existing knowledge and resources. This statement is meant to imply that no developmental or operational smoke tests should be conducted without the knowldge and concurrence of the leadership.

(7) The leadership should consider the test plans of items other than EO systems to determine if smoke testing is required.

Finally, it should be pointed out that this report does not advocate an overreaction to smoke or overtesting of systems in smoke even though an elaborate test structure is outlined. The structure should help the leadership, the members, and the users to understand the needs and methods of smoke testing and how and when to apply those methods.

In general, the structure concept and testing approach described in this report are shared by many members of the smoke community within DARCOM. There will, of course, be some differences of opinion relating to the roles of the leadership organizations, as well as to the very broad scope of testing described here. There should, however, be no disagreement with the call for a comprehensive approach and strong leadership in an overall organization of existing resources. The HDL team offers in this report a working guide or plan for tests to get a documented course of action underway. As this plan is implemented by the leadership organizations, changes or innovations will be instituted because of the generation of improved ideas or because of practical limitations. Some test philosophy and structure will evolve, and the degree to which they efficiently meet the real needs of the Army will be strongly dependent upon the capabilities and resources of the leadership organizations.

Several individuals have most influenced the HDL team in the writing of this report: H. Fallin of AMSAA; L. Dominguez of TRASANA: J. Steedman of TECOM; D. Johnson, Chairman of the Smoke-Aerosol Working Group of the JTCG; and the Project Manager for Smoke, COL H. Shelton.

Glossary

AEPG	Army Electronic Proving Ground
AMSAA	Army Material Systems Analysis Activity
ARO	Army Research Office
ASAP	Army Scientific Advisory Panel
ASL	Atmospheric Sciences Laboratory
AVSCOM	Army Aviation Systems Command
BRL	Ballistics Research Laboratory
BSI	Battlefield System Integration Directorate
CAC	Combined Arms Center
CACDA	Combined Arms Combat Developments Activity
CDEC	Combat Development Experiment Center
DARCOM	U.S. Army Materiel Development and Readiness Command
DDR&E	Director, Defense Research and Engineering
DPG	Dugway Proving Ground
EA	Edgewood Arsenal
ERADCOM	Electronics Research and Development Command
FSTC	Foreign Science and Technology Center
HDL	Harry Diamond Laboratories
JTCG	Joint Technical/Coordinating Group for Munitions
JTCG/WG	Joint Technical Coordinating Group/Working Group
MERADCOM	Mobility Equipment Research and Development Command
MERDC	Mobility Equipment Research and Development Center
MICOM	Army Missile Command
NAD	Naval Ammunition Depot
NVL	Night Vision Laboratories
NWC	Naval Weapons Center
OMEW	Office of Missile Electronic Warfare
OTD	Office of Test Director
OTEA	Operational Test and Evaluation Command
TCATA	TRADOC Combined Arms Test Activity
TECOM	Army Test and Evaluation Command
TRADOC	Training and Doctrine Command

LITERATURE CITED

(1) Requirements and Recommendations for a Smoke Technical Data Center, Analytics Inc. (13 December 1975) submitted to the Smoke Program Office, Edgewood Arsenal under contract DAAA1576C0005.

(2) William H. Pepper, Limited Visibility Operations Assessment (Phases I and II), Harry Diamond Laboratories TM-77-16 (December 1977). (SECRET NO FOREIGN DISSEMINATION)

(3) S. A. Schleusener, J. D. Lindberg, K. O. White, and R. L. Johnson, Spectrophone Measurements of IR Energy Absorption by Atmospheric Dust, Applied Optics, 15, No. 10 (October 1976).

(4) V. E. Zueu, M. J. Kobanov, and B. A. Savellev, The Limits of Applicability of the Bouguer Law in Scattering Media for Collimated Light Beams, Izv. Atm. and Oceanic Phys., 3, 7 (1967).

(5) W. E. K. Middleton, Vision through the Atmosphere, University of Toronto Press (1952).

(6) H. Van de Hulst, Light Scattering by Small Particles, John Wiley & Sons, New York (1962).

(7) G. Mie, Ann, Physik, 30, (1908), 377.

(8) R. W. Withers, Quantitative Measurement of Aerosol Backscatter Using a Fan-Beam Active Optical Sensor, Motorola Inc., presented at the First Tri-Service Optical Fuze Technology Sumposium, sponsored by the Joint Technical Coordinating Group for Munitions Development, Working Party for Fuzes (May 1976).

(9) D. Giglio, B. Rod, and H. Smalley, Nephelometer Mapping of Backscatter and Attenuation Coefficients of Clouds, Harry Diamond Laboratories TR-1660 (February 1974).

(10) C. R. Odom, Measurement of Atmospheric and Smoke/Aerosol Parameters During CM TESTS, presented at the Seventh Department of Defense Conference on Laser Technology, West Point (June 1976).

(11) B. M. Herman, S. R. Browning, and J. A. Reagan, Determination of Aerosol Size Distributions from LIDAR Measurements, Journal of Atmos. Sci., 28, 763 (July 1971).

LITERATURE CITED (Cont'd)

(12) H. Dessens, Les Noyaux de Condensation de L'Atmosphere, La Meteurol, 321327 (1947).

(13) Visibles et Infraouges a Travers Le Brouillard, Comptes Rendus 230 (1950), 565-567.

(14) W. H. Leonard and J. E. Kirshtein, Tactical Operations Assessment, Attack Helicopter--Daylight Defense Experiment, CDEC Experiment 43.6, Army Missile Command Report No. RB-TR-72-1 (March 1972).

(15) T. J. Gleason and M. E. Sword, Intervisibility Beacon System, Phase I Final Report, Harry Diamond Laboratories PR-74-1 (June 1974).

(16) T. J. Gleason, M. E. Sword and R. L. Gorman, Intervisibility System, Phase II Final Report, Harry Diamond Laboratories PR 74-2 (August 1974).

APPENDIX A.--TESTING ELECTRO-OPTICAL SYSTEMS IN A SMOKE ENVIRONMENT

CONTENTS

Editor's Note: Originally published by the Army Test and Evaluation Command--editorially reviewed by HDL.

A-1. BACKGROUND

Electro-optical (EO) guided weapon systems and thermal viewing devices at this time are being emphasized by the Army because of their great potential; however, there is concern about the possible reduced effectiveness of these types of systems when used in abscurant countermeasure environment. Unfortunately, past testing, which utilized only limited quantities of smoke and in ways which did not represent either U.S. or Soviet doctrine, did not provide the necessary information to ascertain the extent of this problem. It is imperative that both the capabilities of friendly systems to operate in a smoke environment and the capabilities of friendly smoke to decrease the effectiveness of enemy EO systems be determined.

Recognizing the growing need for effective testing in this area, the Army Test and Evaluation Command (TECOM) initiated investigations to determine the procedures for testing the effectiveness of smoke and the optimum location for the conduct of such smoke tests. The efforts are still on-going although a great deal of information has been obtained.

A recognition of the problem by Army Materiel Development and Readiness Command (DARCOM) led the Director for Battlefield Systems Integration (BSI) to hold a meeting on 6 May 1976 to develop a DARCOM position for testing EO systems in a smoke environment. At the meeting it was emphasized that

(a) Soviet tactical doctrine includes heavy use of smoke.

(b) U.S. tactical doctrine relies heavily on the use of sensors and weapons systems which could be affected by smoke.

(c) Because of these two points, the Vice Chief of Staff, Army has expressed concern that the U.S. has not been adequately testing the effectiveness of its EO systems in a smoke environment.

As a result of the 6 May meeting, DARCOM issued a tasking message on 8 June as follows:

(a) Harry Diamond Laboratories (HDL) will coordinate a joint Training and Doctrine Command (TRADOC)-DARCOM plan for tests to determine susceptibility/vulnerability of EO laser, and IR guided weapons, and target acquisition, target designation and range-finder devices in U.S. and Soviet smoke environments.

(b) The Army Material Systems Analysis Activity (AMSAA), in coordination with TRADOC, will determine testing required to validate TRADOC and DARCOM smoke models.

(c) Edgewood Arsenal (EA) will determine testing requirements to support development and operational testing of new and present U.S. smoke systems.

(d) TECOM will recommend to Headquarters, DARCOM that tests be conducted in support of (a), (b), and (c) of the tasking message above. The recommendation should identify DARCOM and tri-service support activities/capabilities in methodology and instrumentation. The recommendation is also to contain a proposal based on current and future activity capabilities for the conduct of tests in both the near-term and long-term time frame.

This documented effort is in response to the 8 June tasking document.

A-2. PURPOSE OF EFFORT

Provide a recommendation for the conduct of testing in support of:

(a) development of a joint TRADOC-DARCOM plan for tests to determine susceptibility/vulnerability of electro-optic, laser, and IR guided weapons, and target acquisition, target designation, and range-finder devices in U.S. and Soviet smoke environments.

(b) testing required to validate TRADOC and DARCOM smoke models.

(c) development and operational testing of new and present U.S. smoke systems.

The recommendation will identify DARCOM and tri-service support activities/capabilities in the following areas.

(a) <u>Methodology</u>

1. Currently available

2. On-going studies

3. Areas requiring further study

(b) <u>Instrumentation</u>

1. Availability

2. Future requirements,

and will contain a proposal based on activity capabilities (current and future) for the conduct of smoke testing in both the near- and long-term time frame.

A-3. DISCUSSION

The evaluation process is the key to determining both the susceptibility/ vulnerability of EO guided systems in an obscurant environment and, conversely, the effectiveness of the obscurant. The same evaluation procedures and measurements of effectiveness apply for both situations. Only the interpretation of the results differs.

The evaluation process provides the basis for determining data needs; however, there is a problem in that it is physically and economically undesirable to conduct tests under all the conditions for which data are required to determine systems effectiveness. Good prediction models to be used in conjunction with the field testing are desirable. The prediction models give the results to be examined against the effectiveness criteria while the field test data are necessary to.

(a) Validate the model.

(b) Provide input for system evaluation.

(c) Provide performance data to determine the degree to which requirements stated within requirements documents have been met.

The various areas of concern will be discussed separately in the following sections.

A-4. TESTS TO DETERMINE SUSCEPTIBILITY/VULNERABILITY

The joint TRADOC-DARCOM plan for tests to determine the susceptibility/ vulnerability of EO devices in U.S. and Soviet smoke environments has not yet been developed by HDL. However, as part of its effort to support the DARCOM smoke program, TECOM initiated a methodology investigation in FY76 to develop procedures for testing the effectiveness of smoke munitions as screening agents against sensing devices. As previously stated, it is anticipated that the same procedures and measures of effectiveness for evaluating smoke effectiveness will be applicable to determining the susceptibility/vulnerability of EO systems in an obscurant environment. Consequently, the same basic test procedures and test data will be applicable whether testing EO or smoke systems.

There is a requirement for two types of smoke/EO systems evaluation, technical and tactical. TECOM feels that for either the technical or tactical evaluation, the cost would be prohibitive for the total amount of testing required as a basis for evaluating smoke or EO system effectiveness under all conditions of interest. Consequently, TECOM has designed its test methodology effort towards generating known input requirements for prediction models, since these likely will be the primary evaluation tool for smoke/EO systems effectiveness evaluation.

It is also anticipated that the total test and evaluation procedures will range from technical assessments using controlled, highly instrumented tests designed to generate input to predictive models such as the Joint Technical Coordinating Group/Munitions Effectiveness obscuration model to tactical assessments using large-scale field exercises and force-on-force war-game models. Though TECOM's efforts are geared towards the former Testing and Evaluation (T&E) procedures, the results of the on-going effort will be applicable and will supply significant required inputs to the latter T&E procedures.

Before the total testing requirements for tactical assessments can be determined, the systems to be evaluated must be identified and the tactics and doctrine for use of the systems in an obscurant battlefield environment must be developed. In addition, the input requirements of the evaluation tools must be identified. To date, only the systems to be evaluated have been identified.

A-5. VALIDATION OF MODELS

Obscuration models of various degrees have been or are being developed by Picatinny Arsenal, Harry Diamond Laboratories, Frankford Arsenal, Missile Command, Army Aviation Systems Command, Night Vision Laboratories, JTCG/ME, and AMSAA. Neither a definite identification of models to be used to evaluate the technical and tactical effectiveness of smoke nor a statement of testing required to validate these models has been made as yet by AMSAA which has this assigned responsibility.

As a major step towards resolving this problem, AMSAA has just recently formed a Smoke/Aerosol Task Force to coordinate all of their smoke activities. One of the stated key efforts of that Task Force will be to identify methodology, data gaps, and necessary testing to support the new Project Manager for Smoke. In its reply to a TECOM request for information on model test requirements, AMSAA stated that it would be premature to respond at this time since its Task Force had just begun work. Discussion with the task team leader, Dr. Herbert Fallin, indicates that AMSAA is considering a force-on-force model which will use the JTCG modified obscuration model as a significant subroutine for smoke/EO effectiveness evaluation.

Meetings of the JTCG/ME Smoke/Aerosol Working Group (SAWG) and the DARCOM smoke community, which have been attended by the TECOM smoke point-of-contact, indicate a strong leaning to the JTCG/ME obscuration model, as modified by AMSAA, as a primary technical evaluation tool. TECOM feels that any model designed to evaluate obscuration effectiveness will require the same basic input data required by the JTCG/AMSAA model and, therefore, has designed its on-going smoke test methodology efforts around that model.

The on-going TECOM methodology smoke efforts have been planned and are being conducted in collaboration with AMSAA to assure that the resulting test procedures and test data are applicable to the needs of the models.

A-6. DEVELOPMENT TESTING (DT) AND OPERATIONAL TESTING (OT) OF NEW AND PRESENT U.S. SMOKE SYSTEMS

The only DT/OT requirements which have been identified to TECOM by EA in response to a DARCOM directive are the Armor Vehicle Smoke Program, 155-mm XM761 White Phosphorus (WP) smoke projectile, and the "2.75-in." XM259 WP smoke rocket. EA in its reply to the DARCOM tasking message indicated that a list of testing requirements based on inputs from other participants would be addressed separately with TECOM when inputs were received from those participants. Until that time TECOM will continue to develop test procedures based on general concepts of smoke/obscurant systems.

The test techniques presently being developed by TECOM should be sufficient to satisfy the immediate DT needs, since EA and TECOM have been working in close coordination on DT requirements of smoke systems. In fact, the on-going TECOM methodology investigation/test to develop effective obscurant test procedures was initiated because of a need for determining the effectiveness of the XM761 smoke projectile.

The specifics of OT requirements will be determined when the AMSAA force-on-force evaluation model is developed and input requirements are identified. The OT requirements are in general expected to require the operation of both small- and large-size tactical units trained to operate in a smoke environment using TRADOC doctrine and tactics developed for such operations.

The adequacy of the developed TECOM test procedures for OT use and the ability to modify them to make them applicable to OT depends on the OT requirements, which must still be defined in some detail.

A-7. TESTING CAPABILITY

In order to accomplish the required development testing, the tester must be able to accomplish the following as a function of time and for a variety of test conditions (e.g., environment, range, target).

(a) Disseminate the obscurant.

(b) Measure the obscurant capability of the cloud in terms of the measures of effectiveness.

(c) Measure the physical characteristics of the cloud.

(d) Correlate the physical characteristics of the cloud with the degree of obscuration.

A description of the required testing and the existing test capabilities follows.

The organizations examined for test capability in this area are

TRADOC	Training and Doctrine Command
OTD	Office of the Test Director for Joint Services Electro-Optical Guided Weapon Countermeasures Test Program
NWC	Naval Weapons Center (China Lake, CA)
NVL	Night Vision Laboratories
OMEW	Office of Missile Electronic Warfare
NWSC	Naval Weapons Support Center (Crane, IN)
FA	Frankford Arsenal
PA	Picatinny Arsenal
EA	Edgewood Arsenal
BRL	Ballistics Research Laboratory
YPG	Yuma Proving Ground
ARMTE	Army Materiel Test and Evaluation
EPG	Army Electronic Proving Ground
APG	Aberdeen Proving Ground
JPG	Jefferson Proving Ground
DPG	Dugway Proving Ground

With the possible exception of the Army Missile Command (MICOM) and NVL for limited conditions, only TECOM, TRADOC and NWC have the range area in which to conduct required field testing. All other organizations have only support capability.

Obscuration dissemination.--In order to test in an obscurant environment, it is necessary to create the environment. Although there are a number of ways to generate the obscuration environment, they generally can be grouped into roughly two categories:

(a) Use of field techniques, e.g., smoke pots, projectiles, and generators. All organizations with range area are able to create the smoke environment in this manner.

(b) Create the desired environment by other than standard procedures. An example would be for an organization to reproduce the enemy smoke environment using our knowledge of its characteristics. The primary capabilities exist at DPG, NWC, at China Lake, and EA.

Measuring Obscurant Capability.--All organizations have the capability to measure visual obscuration.

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Measuring Obscurant Capability.--All organizations have the capability to measure visual obscuration.

(a) The measurement of EO system performance requires a greater degree of technology. To measure EO system performance it is necessary to:

(1) Generate the signal that is to be measured.

(2) Determine how the signature is degraded from the target to the sensor by measuring the change of signal at the sensor.

(3) Correlate the capability of the receiver to function based on the signal that is received.

(b) Generation of signal. All the organizations which were studied have or could easily develop the capability to generate a signal. Except for passive IR, all signals are generated by an outside source (e.g., lasing on target) which is easily acquired. The passive IR signal is generated by the actual targets or a black box IR source, neither of which represents a major problem.

(c) Measurement of signal intensity at receiver. In all cases the greatest capability to measure signal intensity exists at WSMR because of the collocation of ARMTE, OMEW, and OTD, all of which have extensive experience which is immediately applicable to the obscuration environment. This area will be discussed in greater detail in the Test Methodology and Instrumentation Section.

(d) Correlate capability of receiver to function. This is a technical capability that exists throughout all the services. White Sands Missile Range (WSMR), because of the collocation of ARMTE, OMEW, and OTD, would have an excellent capability. Other good capabilities would exist at MICOM and NVL.

Measuring Physical Characteristics of the Cloud.--The determination of cloud characteristics is a unique capability that exists primarily at DPG (with the exception of a limited capability at NWC China Lake, CA). DPG's capability exists because of the instrumentation and facilities

which have been developed and installed at DPG for its basic mission of T&E of chemicals and biologicals. Most of this capability is applicable to either static or dynamic EO/smoke testing.

Correlation of Cloud Characteristics and Degree of Obscuration.--No organization has the total required capability. It will take combined efforts of DPG (cloud characteristics) and those organizations most knowledgeable in determining EO system performance to effectively conduct the required correlations.

A-8. TEST METHODOLOGY AND INSTRUMENTATION REQUIREMENTS

A TECOM assigned responsibility is to identify DARCOM and tri-service support activities/capabilities in the areas of methodology and instrumentation.

Methodology.--The methodology is concerned primarily with the means of measuring the physical and obscuration characteristics of the cloud and interpreting this information in terms of either cloud or weapon system performance.

(a) Currently available methodology:

There is little existing test methodology for determining the effectiveness of smoke as an obscurant or conversely for determining the effectiveness of EO systems in a smoke environment. Most available test techniques lead to a description of the physical and temporal characteristics of the cloud but do not provide the means to collect the obsucration information nor the means to interpret this information in terms of performance. In addition, although there has been considerable testing of EO systems in a smoke environment by various DoD agencies, there is no adequate existing documented standard test procedure for either the test or the evaluation of EO systems effectiveness in a smoke environment. The test and evaluation procedures (instrumentation, data, test set-up data-reduction, and data-analysis techniques) vary considerably from test to test making it difficult, if not impossible, to compare results of one test to the results of another test. There is a serious need for development and documentation of standard EO/smoke test procedures.

(b) On-going studies:

(1) During the second half of FY76, TECOM initiated a methodology pilot study at DPG to develop the procedures for testing the effectiveness of smoke munitions as screening agents against visual sensors and analyzing the collected data. Since then the investigation has been expanded to include development of procedures for determining the effectiveness of laser seeker/designators and IR thermal imagers in a

smoke environment. The techniques are being developed, as a minimum, to generate the data needed as input to the JTCG/ME (AMSAA) obscuration model. The developed techniques will be validated by a limited dynamic firing program followed by reduction and analysis of the data. The investigation, which will be completed in FY7T, is limited to detection of stationary targets. The results of the investigation will be applicable both to testing smoke effectiveness and the testing of the performance of both visual and EO systems in a smoke environment. All developed test and analysis procedures will be fully documented. This is a joint effort of TECOM, AMSAA, EA, and OMEW.

(2) PA indicates that on-going test methodology studies are being developed based on their existing general-purpose illuminating effectiveness model. Discussions with the model developer indicate that this model is similar to but not as extensive in its capability as the JTCG/AMSAA obscuration model. The PA test methodology effort is very limited in scope.

(c) Areas requiring further study:

(1) At the May 1976 meeting of the JTCG/ME SAWG it was agreed that there is a critical need to develop a standardized listing of measurements that should be made during tests, to include units and techniques of measurements. The SAWG included funds in its proposed FY77 budget for DPG to develop a list of standard measurements to be made in all smoke testing. Although the budget request was disapproved, it is anticipated that the on-going DPG methodology effort will result in such a list. It is known that important areas must still be examined, such as moving targets, large area screening, multiple target and EO sensor combinations, target acquisition and target tracking, tactics, doctrine, and the ability of soldiers to operate in a tactical smoke environment.

(2) The science of testing in smoke environments is in its infancy. Continuing work will be required for an extensive period of time.

<u>Instrumentation</u>.--As part of its efforts to support the DARCOM smoke program, TECOM designated DPG as its smoke test center and DPG was assigned the task of determining the instrumentation required to support testing in a smoke environment.

Some instrumentation is available at non-DARCOM activities. TRADOC has only limited capability. NWC appears to have a capability which must still be defined. The Office of the Test Director, Joint Services Electro-Optical Guided Weapons Countermeasures Test Program (OTD) has an extensive E) test instrumentation capability. OTD's Mobile Instrumentation Facility (MIF) consists of four vans capable of being transported by road, rail, or air. The vans are equipped with some 1.5 million dollars of countermeasures test equipment, much of which could be used in testing EO systems in a smoke environment. Because of its extensive instrumentation capability, OTD is considered a prime source for instrumentation support of DARCOM EO/smoke testing.

APPENDIX A

Overall, an extensive EO measurement capability exists at WSMR. This is true because for a number of years, ARMTE has been preparing for testing sophisticated tracking systems, OTD has been preparing to test laser-guided weapons against countermeasures and OMEW has been preparing to test missile system vulnerability against electronic warfare, all of which are closely associated with the evaluation of obscuration effectiveness. In addition to WSMR, and as a result of TECOM's efforts in support of the DARCOM smoke program, DPG had most of the EO instrumentation required for effectiveness testing by the end of FY7T.

The instrumentation required for determination of cloud characterization is a unique capability that exists primarily at DPG, with the exception of a limited capability at NWC, China Lake, CA. DPG's capability exists because of the instrumentation and facilities which have been developed and installed at DPG for its basic mission of test and evaluation of chemical and biological materials. DPG has several million dollars in capability devoted to test and analysis of cloud characteristics. Most of this capability is applicable to either dynamic or static EO/smoke testing.

Other Information.--The organizations that have been examined for capability can generally be separated into those that have potential for conducting the field tests and those that have support capability only. A major requirement to conduct the field tests is the availability of a test area that can be used for this purpose. The organizations that will conduct the tests must have the following attributes:

Large test area
Remoteness from populated areas
Meteorological capability
Variety of terrain
Variety of climate
Maintenance capability
Rail transportation
Air field
Expertise
Capable of timely support of smoke test requirements

Considering the DARCOM organizations, the primary capability to conduct the necessary tests exists at the TECOM proving grounds. Within TECOM, DPG is considered to have the best capability.

A-9. CONDUCT OF SMOKE/OBSCURANT TESTING (NEAR AND LONG TERM)

A sufficient capability associated with the present state-of-the-art exist within the Army. No one organization has all the required capabilities to conduct effective smoke/obscurant testing. In order to be able to test effectively, it will be necessary to improve the capability no matter where the decision is to test.

TECOM recommends that near-term testing of the type referred to by DARCOM (susceptibility/vulnerability of EO systems to smoke, validation of smoke models, testing smoke systems) be conducted at DPG and that EO instrumentation and expertise assistance, as required, be obtained from other DARCOM sources and the OTD to support DPG. DPG is recommended because DPG

(a) has extensive capabilities in terms of instrumentation, laboratory facilities, and expertise required for gathering and analyzing cloud characteristic information.

(b) has most of the EO instrumentation required for smoke/EO effectiveness testing.

(c) has ranges capable of handling the new extended range munitions.

(d) ranges are remotely located in relation to populated areas.

(e) can handle the anticipated increased work-load effectively because of the recent decrease in CB testing, a primary mission at DPG.

(f) is actively involved in developing EO/smoke test methodology.

(g) has the ability to create the enemy smoke environment.

Table A-I shows testing requirements and capabilities of various organizations to meet these requirements. Within the Army DPG has the best overall capability. Within the Navy the best overall capability exists at NWC. The primary DPG advantage is associated with the ability to determine cloud characteristics and to create the environment.

For long-term testing beyond FY77, TECOM recommends that DPG develop an independent capability in terms of EO instrumentation and expertise. This would cost approximately $165,000 and would require an additional civilian EO space on DPG Technical Distribution and Allowance.

TABLE A-1. CAPABILITIES

	TECOM															
	APG	ARMTE	EPG	DPG	JPG	YPG	MICOM	PA	FA	BRL	OMEW	NVL	TRADOC	NWC	NWSC	OTD
I. Disseminate obscurant																
A. Field techniques	X	X	X	X	X	X	X	—	—	—	—	—	X	X	—	—
B. Create environment	—	—	—	X	—	—	—	—	—	—	—	—	—	X	—	—
II. Measuring obscurant capability	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A. Generation of signal																
1. Visual	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2. Electro-optical [a]	—	X	X	X	—	X	X	X	X	X	X	X	—	X	—	X
B. Measure signal intensity																
1. Visual	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2. Electro-optical [a]	—	X	X	X	—	X	X	X	X	X	X	X	—	X	—	X
III. Determine cloud characteristics	—	—	—	X	—	—	—	—	—	—	—	—	—	X	—	—

[a] No one activity has a complete capability.

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